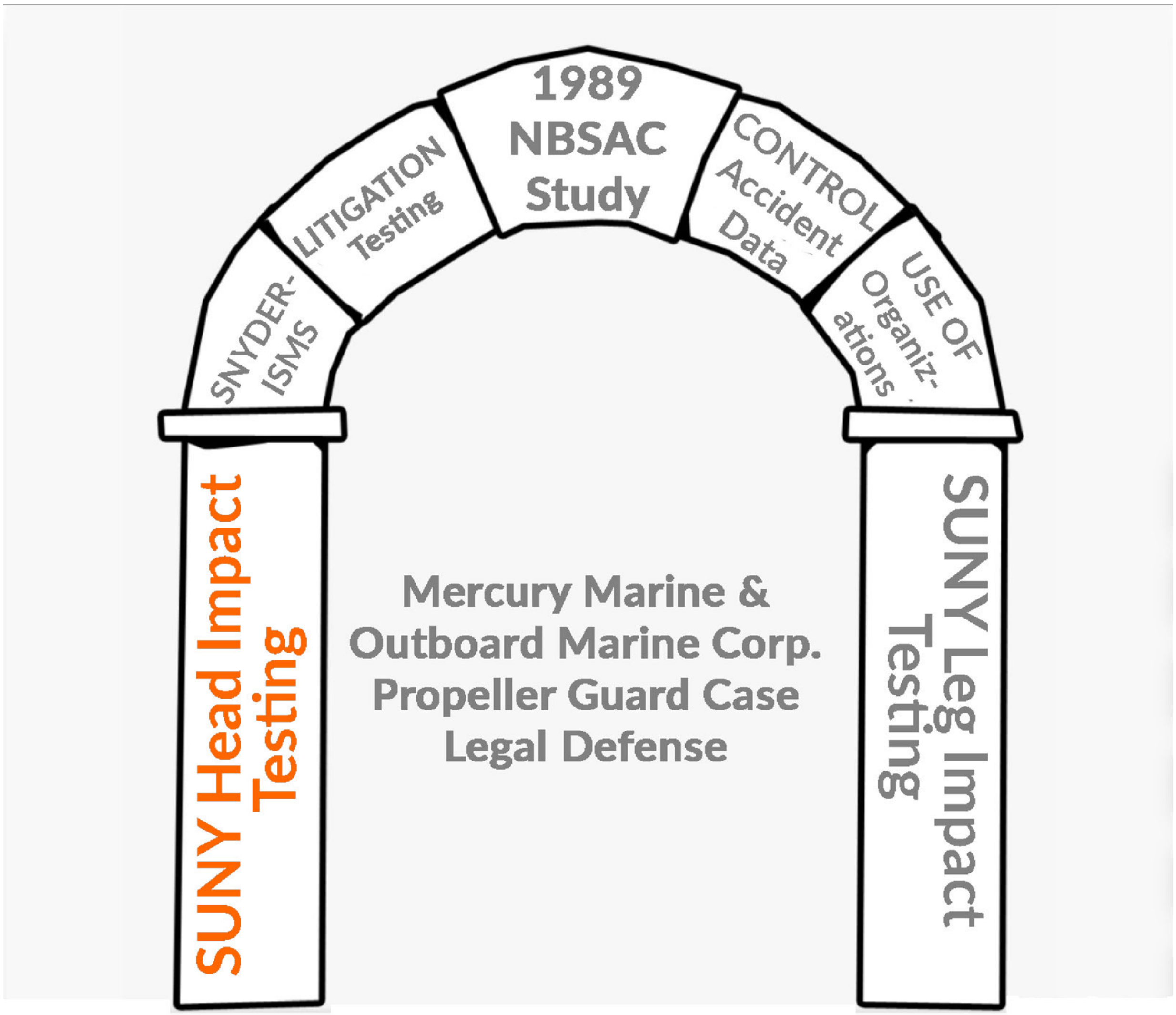

Volume III: Head Impact Study

PropellerSafety.com

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Abstract: Mercury Marine and OMC worked together in the late 1980s and early 1990s to develop a defense against propeller guard lawsuits.

The U.S. Coast Guard 1989 National Boating Safety Advisory Council (NBSAC) propeller guard subcommittee report became the keystone of their defense. It does not get better than having the U.S. Coast Guard officially approving the recommendation, "The U.S. Coast Guard should take no regulatory action to require propeller guards." while repeating many of the industry's objections to propeller guards.

The report was quickly propped up and enhanced by two 1990 underwater impact studies conducted at State University of New York (SUNY) at Buffalo.

This volume, third of a series of four, addresses the underwater head impact study led by Michael W. Scott of Biodynamic Research Corporation.

Very basically, a chair was placed on the bottom of a very large donut shaped 8 foot deep pool. A crash dummy was placed in the chair. An outboard motor with a propeller guard assembled to it was swung around the pool on a long arm to strike the dummy in the head with the propeller guard.

Those who previously critiqued this study are aware stiffness of the crash dummy's neck, tethering the crash dummy, and of the study being funded by Mercury and OMC are known issues with this study.

We will be looking into those and several previously unexplored areas such as:

1. *Tests conducted with an open propeller were expressly forbidden.*
2. *Several issues with crash dummy biofidelity (how accurately its response represents human response) for these specific conditions.*
3. *Inflating the dummy to prevent leaks impacts biofidelity.*
4. *They did not verify crash dummy data with one or more cadavers when testing outside of normal crash dummy parameters.*
5. *The level of involvement of Mercury and OMC legal departments and their legal representatives in the study.*
6. *Several edits of the research paper, with each edit looking more favorable from the industry's perspective.*
7. *Roving authorship of the study (different authors listed over time).*
8. *Use of the 5/16 wire version of Mercury's propeller guard, vs. the 1/4 inch wire version the Marine Corps switched to. (guard stiffness is related to injury severity).*
9. *Simulating propeller thrust allowed the industry to test at zero trim (vertical leading edge of the drive), leading to more challenging impacts (more challenging to slide off the guard).*
10. *Error in added mass calculations in Scott's Figure 3.*

We also expose some previously identified techniques used by the boating industry in our coverage of the 1989 NBSAC report.

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Appendices

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Introduction

As mentioned in previous volumes, 1988 - 1991 was an especially difficult time for Mercury Marine and Outboard Marine Corporation (OMC) with several propeller injury lawsuits being filed against them. Plaintiffs claimed Mercury and OMC drives should have propeller guards.

Mercury and OMC had a mutual protection relationship in trying to find relief from these lawsuits. Relationships were being formed prior to May of 1988[1] when the U.S. Coast Guard National Boating Safety Advisory Council (NBSAC) formed a propeller guard subcommittee. Mercury and OMC both had representatives on the subcommittee. In addition, Dick Snyder, Mercury's long time expert witness in boat propeller cases was closely involved with the subcommittee.

Mercury and OMC were also involved in a propeller guard project for the U.S. Marine Corps in this era. See **Volume II**.

Dick Snyder testified underwater propeller guard impact studies grew from a discussion he had with John Snider and Peter Fuller at a seminar on injuries.[2] Snyder was talking with them about their work with cadavers and motorcycle accidents, and the potential to do similar research underwater.

State University of New York (SUNY) at Buffalo has a 200 foot in circumference donut shaped pool originally constructed for testing humans in special environments. The facility is known as the Center for Research and Education in Special Environments (CRESE).

The boating industry has since used the facilities for several propeller guard studies.

If you are unfamiliar with tank at SUNNY see our video[3] or read any of the studies performed there.

Data for the head impact study was collected in December 1990, along with the leg impact data discussed in **Volume IV**.

Together, these two studies support the 1989 NBSAC subcommittee on propeller guards report as seen on the cover page of this volume.

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[1] For example: Alex Marconi (OMC corporate lawyer) letter to Dick Snyder (Mercury Marine propeller guard expert) regarding a Chicago Tribune story and a National Public Radio story on an incident in which a pelican (bird impact) caused the crash of a bomber. Marconi wrote of how this could bolster their position with a vivid example of kinetic energy and mass. Letter dated January 26, 1988.

[2] Richard Snyder deposition. Robert Leroy Ard vs. Brunswick Corporation. Circuit Court of Jackson County, Missouri, at Kansas City. Case No. CV95-23303. Volume 1. Pages 58-60.

[3] State University of New York (SUNY) CRESE pool video clipped from 1991 Mercury video.
12 second mp4 video.
http://www.propellersafety.com/wordpress/wp-content/uploads/SUNY-propeller-test.mp4

The Purpose of the Underwater Head Impact Paper Changed

The original **purpose of this research is clearly stated** in the Introduction of the preliminary version of Scott's report:

> *"In May of 1988 the U.S. Coast Guard requested the National Boating Safety Advisory Council (NBSAC) to assess the feasibility of using propeller guards to protect submerged individuals from spinning propellers on outboard motors. The NBSAC's report, presented on November 7, 1989, recommended that the Coast Guard take no regulatory action requiring guards on outboard motors (Reference 1). One of the arguments presented against the use of propeller guards was that the "guards may prevent cuts from body contact with a propeller but substitute the potential of blunt trauma injury, which becomes increasingly significant at speeds over 10 mph"" (Page 20. Ref. 1)*
>
> *"The concern that the use of propeller guards **may produce a different injury mechanism was based on theoretical analysis with no direct experimental evidence available to support it.** This research program was undertaken to investigate the potential for blunt injury in underwater impacts with cage type propeller guards. This research was sponsored by Mercury Marine and Outboard Marine Corporation (OMC)."*

Summing it up, the 1989 NBSAC study recommended U.S. Coast Guard take no action to require propeller guards on outboard motors in part because propeller guards may prevent propeller cuts but may cause blunt trauma injuries in doing so.

The authors note, blunt trauma concerns raised in NBSAC's final report were not supported by any direct experimental evidence. The current underwater impact testing program was undertaken to investigate potential for blunt trauma injury from propeller guard impacts.

The **purpose of this underwater propeller guard impact research was restated** in the introduction of the SAFE Journal version of Scott's paper:

> *"In May of 1988 the U.S. Coast Guard requested the National Boating Safety Advisory Council (NBSAC) to assess the feasibility of using propeller guards to protect submerged individuals from spinning propellers on outboard motors.The NBSAC's report, presented on November 7, 1989, recommended that the Coast Guard take no regulatory action requiring guards on outboard motors. One of the arguments presented against the use of propeller guards was that the "guards may prevent cuts from body contact with a propeller, but substitute the potential of blunt trauma injury, which becomes increasingly significant at speeds over 10 mph. This research project was undertaken to better define the potential for blunt injury trauma to the submerged head when struck by a propeller guard."*

Now, after the research is done, the purpose of Scott's paper changes to better defining the potential for blunt trauma injury to a submerged head when struck by a propeller guard. The purpose is now written as if blunt trauma is going to occur and they are going to define conditions under which it happens.

The 1989 NBSAC study basically divided propeller guard forward facing cross sectional area into two segments. See **Figure 1**.

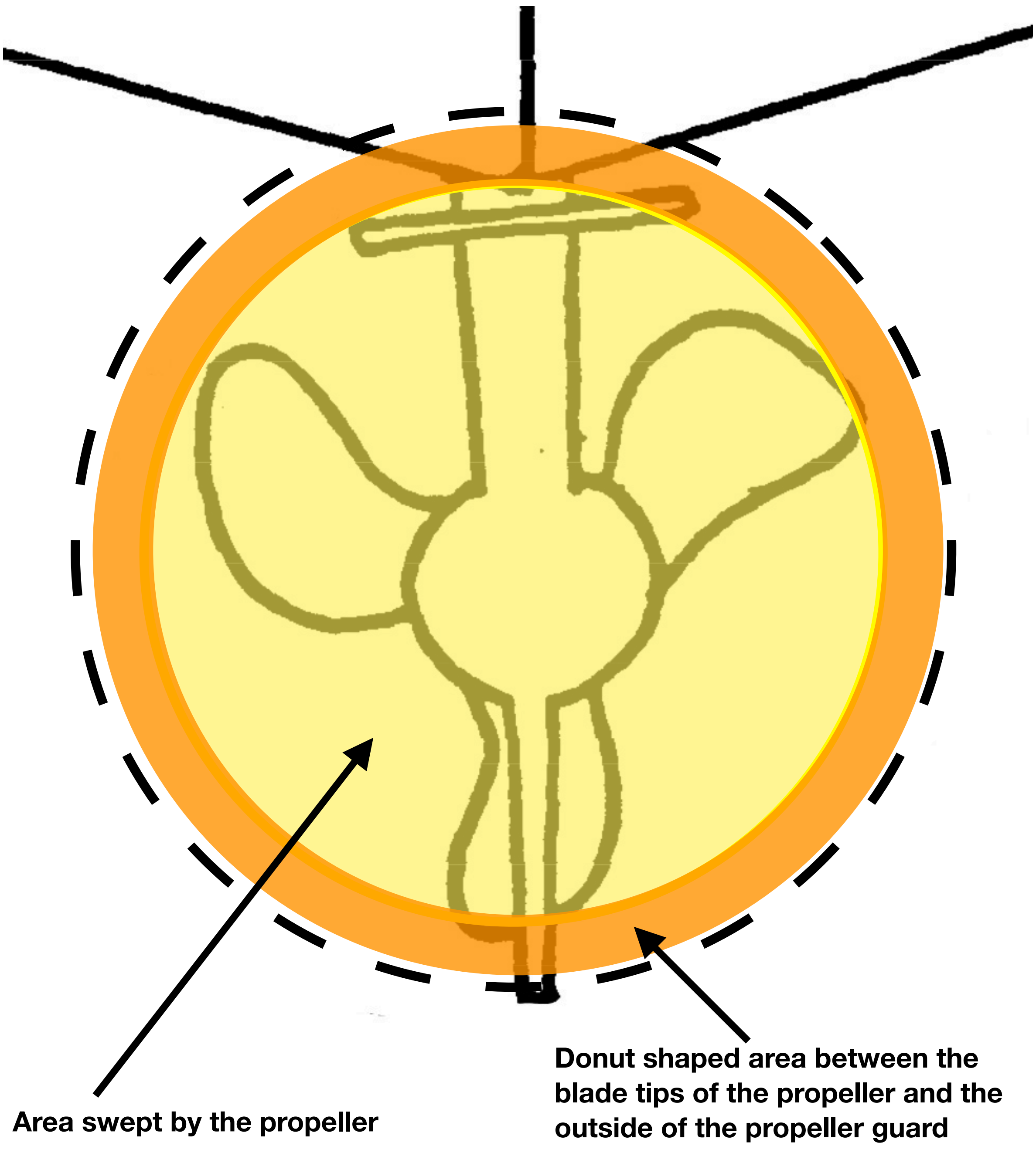

Figure 1: Propeller Guard Areas per 1989 NBSAC Study

The NBSAC propeller guard report said that if you were hit by the yellow area, you would receive blunt trauma injuries which are worse than nice clean propeller cuts.

If you were struck by the orange area, you would not have been struck if the propeller guard was not there. The propeller would have missed you.

Thus which ever area strikes you is worse than an open propeller.

Sidebar about previous research

A few years prior to the propeller guard head impact study, Dr. D. F. Huelke of the University Michigan, well known for his study of automotive impacts, did some work in this area.

He conducted open air crash dummy head impact tests using the lower end of an outboard motor and propeller guards.[4] The addendum is dated March 1988. Huelke's work was never published.

Mr. Huelke presented to the subcommittee on November 14, 1988 but no notes are available. His presentation is listed as #34 dated 12/18/88 in the Prop Guard Subcommittee Appendix C.

Dick Snyder of Mercury Marine reported,[5] *"Professor Don Huelke, University of Michigan, automotive expert on human injury sustained in car crashes has conducted outboard gear case and ring guard head collision studies. He finds that some fatalities can occur as low as 6 mph and even glancing blows could be fatal by 15 mph."*

---

[4] Study of Impact Tests. Dr. D.F. Huelke.
Addendum. Study of Impact Tests. Dr. D.F. Huelke. March 1988.

[5] Dick Snyder of Mercury Marine letter to Jim Getz, NBSAC subcommittee on propeller guarding chairman. Notes-Snyder Presentation, 22 September, 1988 at Rockland, MA. Letter dated October 6, 1988. Page 3.

The current Biodynamic Research Corporation (BRC) study, the underwater head impact study, divides the propeller guard forward facing area into four segments (orange, blue, plus 2 yellow segments) in **Figure 2**.

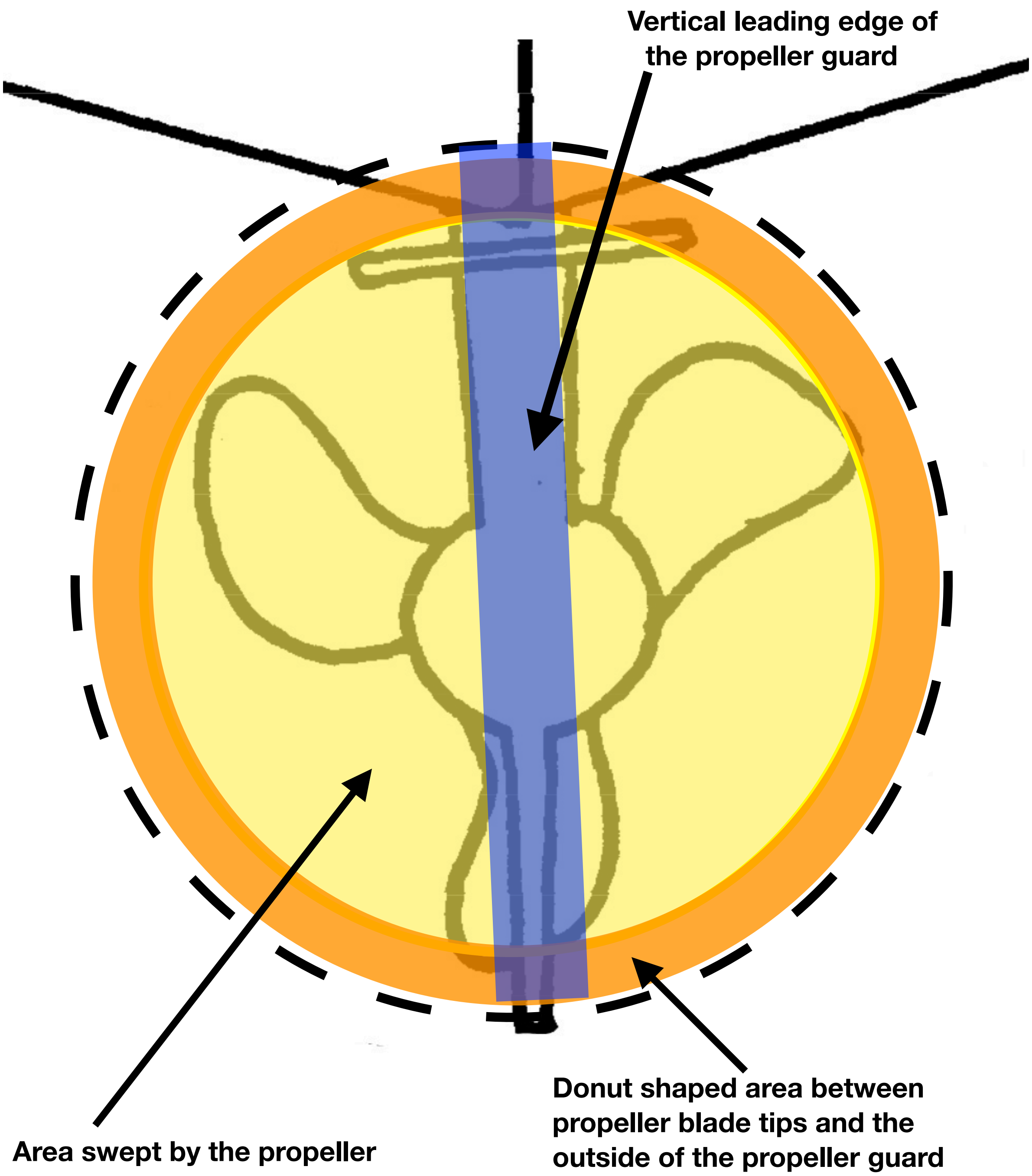

Figure 2: Propeller Guard Areas per 1989 NBSAC Study

The BRC underwater head impact report says that if you are struck by the:

1. blue vertical edge of the propeller guard at speed you will suffer blunt trauma

2. yellow area, you can slide off the guard

3. orange area where the guard is stiffer, you may be knocked unconscious, increasing the probability you will drown

We will return to these findings in our conclusion.

Different Versions of the Head Study

As already illustrated in **The Purpose of the Underwater Head Impact Paper Has Changed**, there are more than one versions of this report.

We have identified four different versions of the head impact study:

1. Preliminary report

Biodynamic Research Corporation
Injury Analysis of Impacts Between A Cage-Type Propeller Guard and a Submerged Head. Preliminary Report.
by Michael W. Scott, Herb Guzman, James V. Benedict, John J. Labra.
Bates stamped 0020624 - 0020802

data begins in Appendix A on 0020709

The final two pages of the preliminary report are a document from Don Kueny of OMC explaining how to use the tilt cylinder to simulate propeller thrust.

2. Non page numbered version of the version eventually published in SAFE Proceedings.

Injury Analysis of Impacts Between A Cage-Type Propeller Guard and a Submerged Head.
by Michael W. Scott, John J. Labra, Herbert Guzman, James V. Benedict, Harry Smith, James Ziegler.

3. Published in Proceedings of SAFE 31st Annual Symposium

Injury Analysis of Impacts Between A Cage-Type Propeller Guard and a Submerged Head.
by Michael W. Scott, John J. Labra, Herbert Guzman, James V. Benedict, Harry Smith, James Ziegler. Published in Proceedings of SAFE 31st Annual Symposium, November 8-10, 1993. Riviera Hotel. Las Vegas, Nevada.
Article begins on page 400 of the Proceedings.
Paper itself is 11 pages in length.

4. Published in SAFE journal

Injury Analysis of Impacts Between A Cage-Type Propeller Guard and a Submerged Head.
by Michael W. Scott, John J. Labra, Herbert Guzman, James V. Benedict, Harry Smith, James Ziegler. SAFE Journal. Vol.24. No.3. Pages 13-23.
Manuscript was received for review 24 March 1994 and accepted for publication 18 July 1994.

Discussion of Versions

The **preliminary report** is a giant report including the raw data.
It is in the form of a preliminary report, including data and charts.

The **unnumbered version** is quite different than the preliminary report. It:

1. takes the material in the preliminary report version, and prepares it to be published in a journal.

2. adds Mr. Smith and Mr. Ziegler as coauthors.

The **Proceedings version** is very close to the unnumbered version, among the differences are:

1. the Proceedings version has a Figure 5 that was somehow left out of the unnumbered version.

2. the Proceedings version has page numbers.

The **Safe Journal version** is very close to the proceedings version, among the differences are:

1. reformatting the layout.

2. The last sentence of the abstract was reworded, apparently in **response to Snyder's review** of the article (see next page).

3. Page 14 of The Safe Journal version (version 4) includes a sentence about the clamps holding the strings holding the dummy in place, "The clamps that held the nylon strings the seat release under a load of less than one lb., so these attachments have no measurable effect on the motion of the ATD in the impacts." This change appears to be in **response to Snyder's review** of the article.

4. The Impact section continued on Page 14 of the Safe Journal version describing the motor ends with three additional sentences describing how the thrust of the motor is simulated. This appears to be in **response to Snyder's review**.

5. The Conclusions section includes the 80% of propeller accidents happen when the boat is on plane, a **Snyderism, apparently directly from his review**.

6. The Safe Journal version has a couple lines noting when the manuscript was received and accepted for publication.

7. Different page numbers because it is in a different publication.

The very first item listed in the bibliography of each of the four versions Scott's paper is the 1989 NBSAC propeller guard report. It is not listed first due to starting with a number because the entry leads with being authored by Getz.

The Preliminary Report version cites Kress's 1991 version of the underwater leg impact study.

Dick Snyder Reviewed the SAFE Journal Version Prior to Publication

A three page form[6] seeking input from reviewers of articles prior to publication was supplied to Dick Snyder for his thoughts about if the article should be published or not.

The form is very basic, consisting of two multiple choice rating questions and some space to write reasons as to the paper's acceptability for publication.

The 2 questions were:

1. Priority Rating - circle one through five. He circled "Highest Priority"

2. Rating - circle one of four answers. He circled "Acceptable"

Dick Snyder attached a two page letter supporting publication of the paper.[7]

Snyder says he did not see any errors in the paper, but identifies several areas he thinks would be of interest to readers.

Snyder's first two points came from the 1989 NBSAC report.

His fifth point includes a *Snyderism* followed by some statistics, and yet another *Snyderism*. *Snyderims* are points Mr. Snyder keeps repeating over and over hoping they will eventually be considered to be true. The two Snyderisms have been bolded.

> *"The impact of the loss of any meaningful head protection above 10 or 15 MPH might be better appreciated when the reader understands that* ***over 80% of the boating fatalities related to the US Coast Guard boating accident category "Struck by Boat or Propeller" occur at planing speed."*** *… "The annual number of fatalities in the U.S. related to this category is generally around 50* ***with about one third of those not directly involving the propeller.*** *(USCG statistics for the years '84, '84, and '86)."*

A version of Snyder's 80 percent at planing speed comment above made it into the conclusion of the SAFE Journal paper.

Snyder told the publisher the abstract of the underwater head impact paper is too conservative and the introduction is too mild. The authors should be bolder in making their points.

He also made a point about the nylon strings used to secure the dummy being released at very light loads that made it into the SAFE Journal version of the paper.

The article review form was another means for Dick Snyder to influence the BRC/Scott paper.

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[6] SAFE Journal manuscript reviewer form. Injury Analysis of Impacts Between a Cage-Type Propeller Guard and a Submerged Head. To be returned to Russell B. Burton.

[7] Richard Snyder, Mercury Marine, letter to Russell R. Burton, DVM, PhD. Regarding the underwater head impact paper by Michael Scott. Dated May 31, 1994. 2 pages.

The Crash Test Dummy

They used a Hybrid III 50 % male ATD dummy

50 percent means it represents the size of a male in the middle of the size range of males. Basically 50 percent of males are bigger and 50 percent are smaller.

ATD - Anthropomorphic Test Device

Since the dummy was to be used underwater various steps were taken to waterproof instrumentation inside the dummy.

The setup is shown in **Figure 3**.

The dummy was pressurized with air to call attention to leaks.

The dummy was weighted down to be at a neutral balance with the water. The dummy was basically floating right above the chair. It was tethered down by nylon strings said to release at less than one pound of tension.

Some critical of this study have focused on the dummy being tied down to the chair. We will leave that discussion to them.

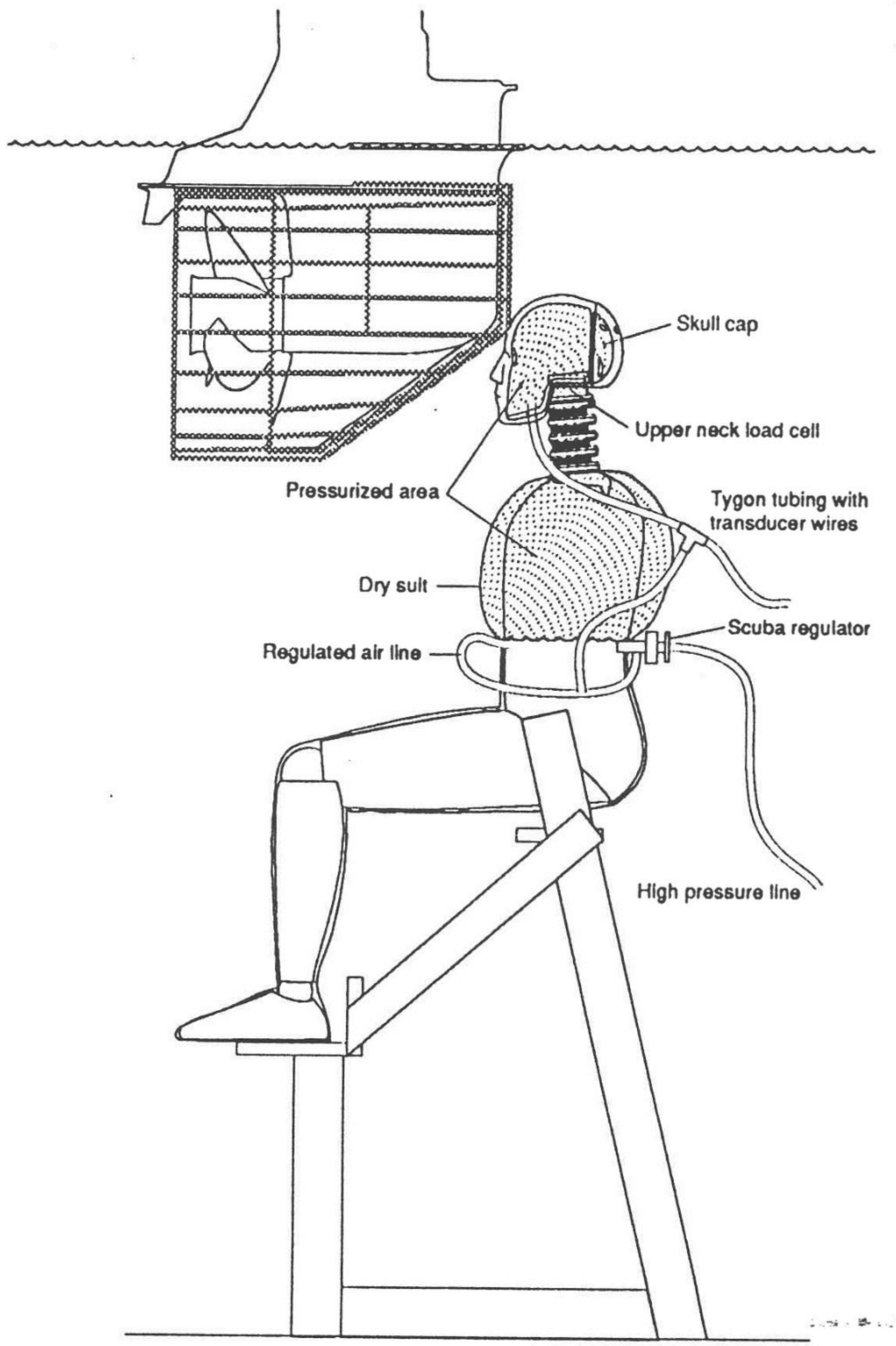

Figure 3: Crash Dummy Position in Tank
image from SAFE Journal

Test Setup to Maximize Impact

We note the dummy in **Figure 3** is setup for the most damage possible from impact with the propeller guard.

1. The human head is our most vulnerable region to impact.

2. The head is forward facing. Our necks have much less stiffness to being struck from the rear.

3. The forehead is aligned to strike the leading edge of the guard at the point in which it begins to bend backwards along the skeg (fin at bottom of the outboard motor).

4. The chest, neck, and head of the dummy have been inflated with pressurized air to keep the internal electronics dry and to spot leaks. Pressurizing the head and neck make them stiffer so they deform less during impact. Less deformation means shorter contact times which lead to greater impact forces.

5. A spring in the Hybrid III crash dummy's neck made the neck several times stiffer that it should have been in axial compression (your head being pushed vertically down toward your chest, like a rock fell on your head).

6. No effort was made to estimate the portion of people struck by propellers that were struck in their head with their body in the orientation they were in the test structure (underwater chair).

7. Also see the **Simulating Propeller Thrust** section (running trimmed down with leading edge of the drive vertical).

Setting the dummy up to be injured in the worst possible way is not representative of the average person being struck by a propeller guard.

A person's body can come into the guard from a number of positions. We suspect the most likely way to be struck in the head is to be ran over or to fall from the boat and be ran over. Even if you just look at odds, heads have four sides and a top. Only 20 percent random chance of being struck from the front if struck in the head from only one side.

Head strikes are fatal more often than other strikes. Freund's 1978 study[8] found 16 of 52, or 31 percent of **fatalities** were purely struck in the head. Only 7 of 171, or 4 percent of **injuries** were purely struck in the head.

The industry is trying to paint propeller guard strikes as unsurvivable of which some but not all may be.

---

[8] Table 11. Detailed Tables. "Struck by Propeller" Accidents - 1978. Kenneth F. Freund. U.S. Coast Guard. Tables Page 3.

U.S. Patent **Sep. 18, 1990** **Sheet 1 of 4** **4,957,459**

FIG. 1

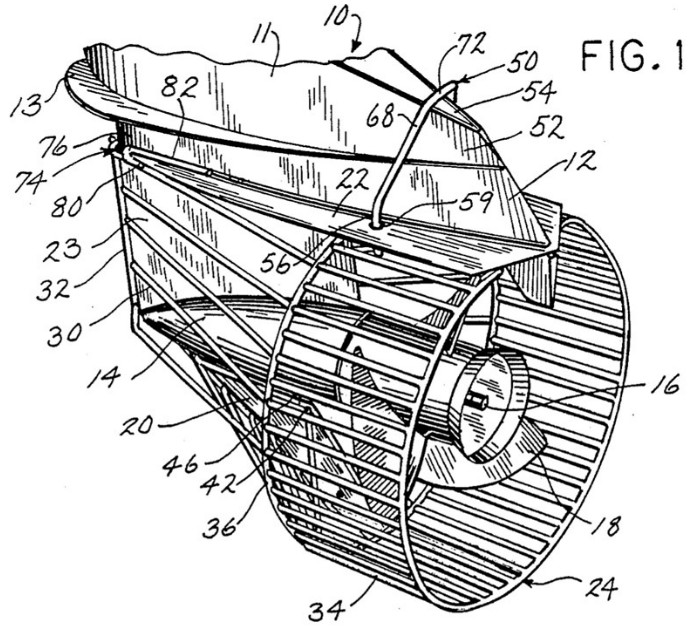

FIG. 2

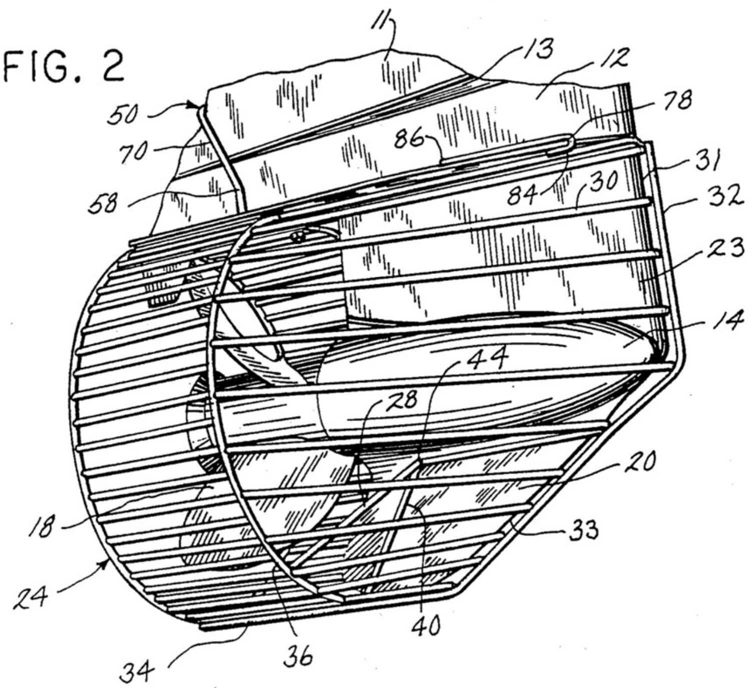

Figure 4: Dick Snyder's Propeller Guard used during the testing

The Motor and Guard

The outboard motor was a 115 horsepower Johnson outboard from Outboard Marine Corporation (OMC). The propeller guard, U.S. Patent 4,957,459,[9] was designed by Dick Snyder of Mercury Marine. It was a version of the propeller guard Mercury Marine sold the U.S. Marine Corps for their River Raiding vessels.

During product development of the guard, the Marines switched from the 5/16 inch thick wire used in this guard to 1/4 inch thick wire to reduce drag.

If the head impact testing had been performed with the 1/4 in wire guard, the propeller guard would have flexed more in some situations, reducing impact to the head.

On many outboard motors the leading edge comes to a point or bullet nose shape in front of the torpedo (long, horizontal, cylindrical section in front of the propeller). The bullet nose area is beneath the portion of the guard striking the forehead in this study.

If the bullet nose area had directly struck the dummy's forehead, and the dummy's head subsequently passed through the open propeller along one side of the other of the gear case while the motor was running and the outboard was engaged in forward gear, a horrific scene would have presented itself.

That is likely why the industry said, there was to be no testing without the guard.

No Testing to be Performed Without a Guard

Don Kueny, then Director of Engineering at OMC wrote a 2 page letter[10] to Edgar Rose, Vice President of Engineering at OMC copied to Tyler Kress, Mike Scott, and Richard Snyder setting up a planning meeting to review the protocol they would be using for underwater impact testing.

Item 2 on the summary stated, "No testing will be done without a Guard." See **Figure 5**.

The project was basically to determine if a propeller guard was better / safer / caused less serious injuries than an open propeller. That is impossible to do without running an open propeller in the same conditions.

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[9] Mercury Marine / Dick Snyder 1989 Propeller Guard. PropellerSafety.com. Gary Polson. July 12, 2012. https://www.propellersafety.com/5151/legal-propeller/mercury-marine-snyder-propeller-guard/

[10] Don Kueny of OMC letter to Edgar Rose, copied to Tyler Kress, Mike Scott, and Richard Snyder regarding a September 27, 1990 meeting about underwater testing. 2 pages. Dated October 8, 1990.

OMC OFFICE MEMO

DATE: October 8, 1990

TO: E. Rose

cc: Tyler Kress
Mike Scott
R. Snyder

FROM: D. F. Kueny

LOCATION: Marine Engineering

SUBJECT: Meeting Regarding Underwater Testing

Purpose of Meeting: To review protocol for underwater impact testing.

Time and Place of Meeting: 9:00 a.m., September 27, 1990, NMMA Business Room, McCormick Place.

Persons Attending: Richard Snyder, Mercury Marine
Mike Scott, Biodynamic Research Corporation
Tyler Kress, University of Tennessee
Don Kueny, OMC

Summary:

1. OMC will supply a Johnson commercial 100 hp. Mercury will furnish appropriate Snyder Guards.
2. No testing will be done without a Guard.
3. Testing will be done in 2 groups, head and limb.
4. Mercury will supply photography.
5. Mike Scott is to furnish a refined protocol and estimated costs by November 4, 1990.

Commitments: Don Kueny will purchase and ship the appropriate outboard pending shipping information from Mike Scott.

Discussion: Testing will be in two general groups, all with a Guard in place along with a propeller free to rotate. Propeller thrust will be simulated with spring force applied to the powerhead. Kueny is to provide gross thrust data.

Figure 5: SUNY Planning Meeting

Biofidelity: Stiffness of Dummy's Neck

Section V. of Scott's preliminary report is titled, Hybrid III Biofidelity.

Biofidelity refers to how accurately the crash dummy represents what would have happened to a real person.

> "*In the axial compression mode (*top of head being forced down toward your chest*), the Hybrid III neck is stiffer than human cadaver preparations which **may** lead to an overestimate of the neck forces developed in these impacts.*" Page V-1.
>
> "*In rotation about the z-axis the Hybrid III neck has also been found to be stiffer than the human serial spine and the measured moments about the z-axis **may** also be overestimated.*" Page V-1.

Scott's paper discusses the guard gripping the dummy's head:

> *"The high neck loads occurred because of the interaction between the guard and the rubber skin, which prevented the head form rotating into extension." PageV-4.*
> Basically the dummy's face became captured by the metal wire frame across the leading edge of the drive and was not allowed to slide along the guard.
>
> "*This interaction, or gripping of the head by the guard, occurred at all impact positions, and **may** be a characteristic of guard contact with soft tissue in general.*" Page V-4.
>
> *"The gripping action enhances the potential for neck and limb injury because the head and impacted limb are not allowed to freely rotate away from the guard, which creates high loads in the neck and the connecting joint of the impacted limb."* Page V-4.
>
> "*One of the main biofidelity questions in this study is the realism of the forces required to break the skin and the accelerations produced in the subsequent metal to metal contact* (under the rubber skin, the dummy's skull is made of aluminum) *that occurred in the centered impacts where the rubber skin broke. Since the Hybrid III was not designed specifically for impacts where the skin would be penetrated, no evaluation of skin penetration characteristics has been done to the best of our knowledge." Page V-1.*

When talking about the donut shaped area in which the guard extends diagonally beyond the tips of the propeller blades:

> *"This additional area due to the structural requirements of the guard in the propeller area, presents a relatively rigid impacting surface that **can** easily break the frontal bones of the face or create high rotational accelerations of the head that **can** cause a loss of consciousness."* Page V-5*.*
>
> *"Conclusions D. General Comment for all Positions: Guard **may** interact with, or grip the soft tissue of the head in such a manner that it carries the head without allowing it to rotate, increasing the chance of neck injury."* Page VI-1

The four uses of "**may**" and two uses of "**can**" above become significant in having confidence in the authors' conclusions.

Without biofidelity of the crash dummy in the manner in which it was used, the study is invalid.

The authors:

1. Made absolutely no mention of the stiffness of Hybrid III crash dummy necks in the SAFE Journal version of the report.

2. Did not investigate / validate if the skin gripping phenomenon which significantly increased forces happens on real faces or not. Also see the later discussion of water making skin slipperier in the **Sliding Head / Lubrication** section.

3. Focused on frontal head strikes. Even if you just look at random odds, heads have four sides and a top. Only 20 percent random chance of being struck from the front if struck in the head from only one side. See later discussion of Thibault's report.

When Dick Snyder reviewed the article for publication he made no mention of the issues above. Instead, he called for making bolder claims.

Scott's Propeller Guard Head Impact paper Reference #10 /Mertz

In 1978, Harold J. Mertz and his co-authors published the first widely known study on axial compression of human necks (like you dove headfirst into a shallow pool and hit your head) in which Hybrid III dummy data was collected and directly compared with reports of individual accidents and their severity. Mertz's work focused on football players striking tackle dummies head first. He developed a chart with "injury" and "no injury" zones based on force and duration of impact. Instead of testing human volunteers or cadavers to verify Hybrid III dummy data, Mertz used data from a few reported severe injuries and fatalities.

In the lower left corner of Page #21 of Scott's SAFE Journal version of the paper (we list as version 4) Scott wrote:

"*One criterion for neck compression injuries has been developed by exposing the Hybrid III ATD to human injury producing conditions."* and they cite their **reference #10,** a sports medicine paper[11] by Harold J. Mertz about spring loaded football tackling dummies and head injuries.

Mertz's sports medicine paper begins by discussing three high school football players allegedly injured by a spring loaded football tackle dummy. The tackle dummy consists of sponge rubber covering metal. It is propelled by springs.

Mertz identified 2 accidents recorded in an even earlier article[12] written by Torg in which the young man's height and weight was known. One survived, and one died. One of the accidents is listed as "allegedly" and the fatality is listed as "reportedly".

Mertz identifies a third injury "not reported in the literature" in which a high school player was "allegedly struck and rendered quadriplegic" by a spring loaded tackle dummy.

Mertz goes on to say Torg and his associates also reported on a group of 8 neck injuries during football games.

All 11 individuals were wearing football helmets but they are not sure what kind of helmet as there were several energy absorption methods in use at that time.

Mertz and his associates setup a simulated test in which they propelled a padded weight at the top of a Hybrid III dummy's head. The crash dummy was laying on his back, strapped to a pallet. His head and neck extending off the end toward the tackle dummy. The crash dummy's hips and knees were flexed.

Mertz and associates learned coaches normally propel the tackle dummy by both springs as the athlete is charging the dummy increasing relative impact velocity. With the crash dummy, they learned the impact had to be squarely on the crown of the helmet to create large axial compressive forces. Page 104.

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[11] An Assessment of Compressive Neck Loads Under Injury-Producing Conditions. Mertz, Hodgson, Thomas, and Nyquist. The Physician and Sportsmedicine. Vol.6. No.11. (1978) .Pages 95-106.

[12] Collision with spring-loaded football tackling and blocking dummies. Torg, Quedenfeld, Thieler, & Lignelli. JAMA 236:1270-1271. 1976

Mertz and associates then wrote, *"We used these observations with the Hybrid III dummy to postulate two references for injurious axial compressive neck forces,* ***because the exact impact conditions for the high school football players who were reportedly injured while hitting spring-loaded tackling blocks were not known****."*

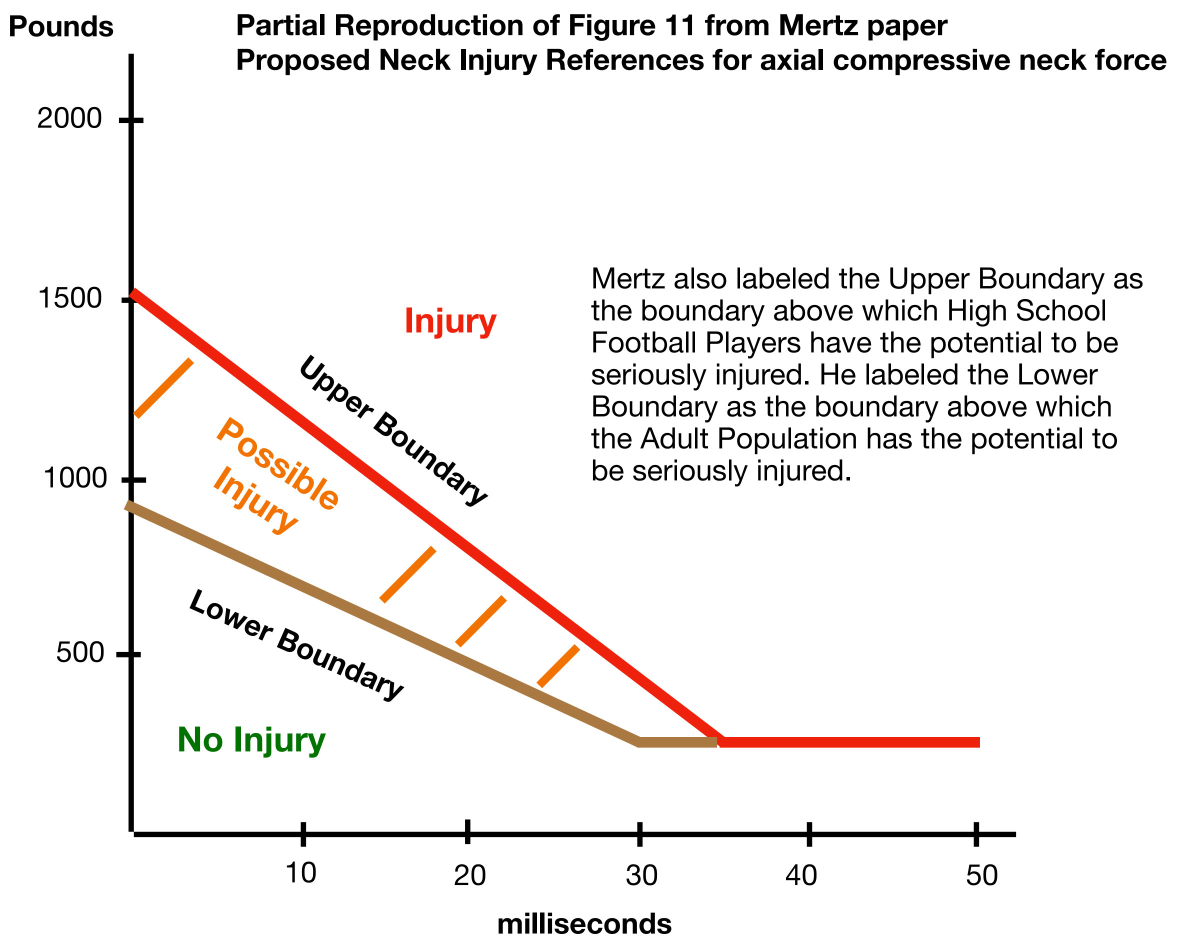

Chart 1: Mertz Axial Compressive Neck Force Boundaries

One injury reference was for helmet #4 with the tackling block propelled at 6.9 meters/second. This represented a football player charging at 1.8 meters/sec with the tackling block at its maximum speed of 5.1 meters/second. This was considered the upper bound (line at which if you were above you would be seriously injured). See **Chart 1**.

The other injury reference used helmet #4 with the tackling block propelled at 5.1 meters/sec representing a stationery player hitting the tackle dummy with the crown of his helmet. This was considered a lower bound (line below which you would not be injured). See **Chart 1.**

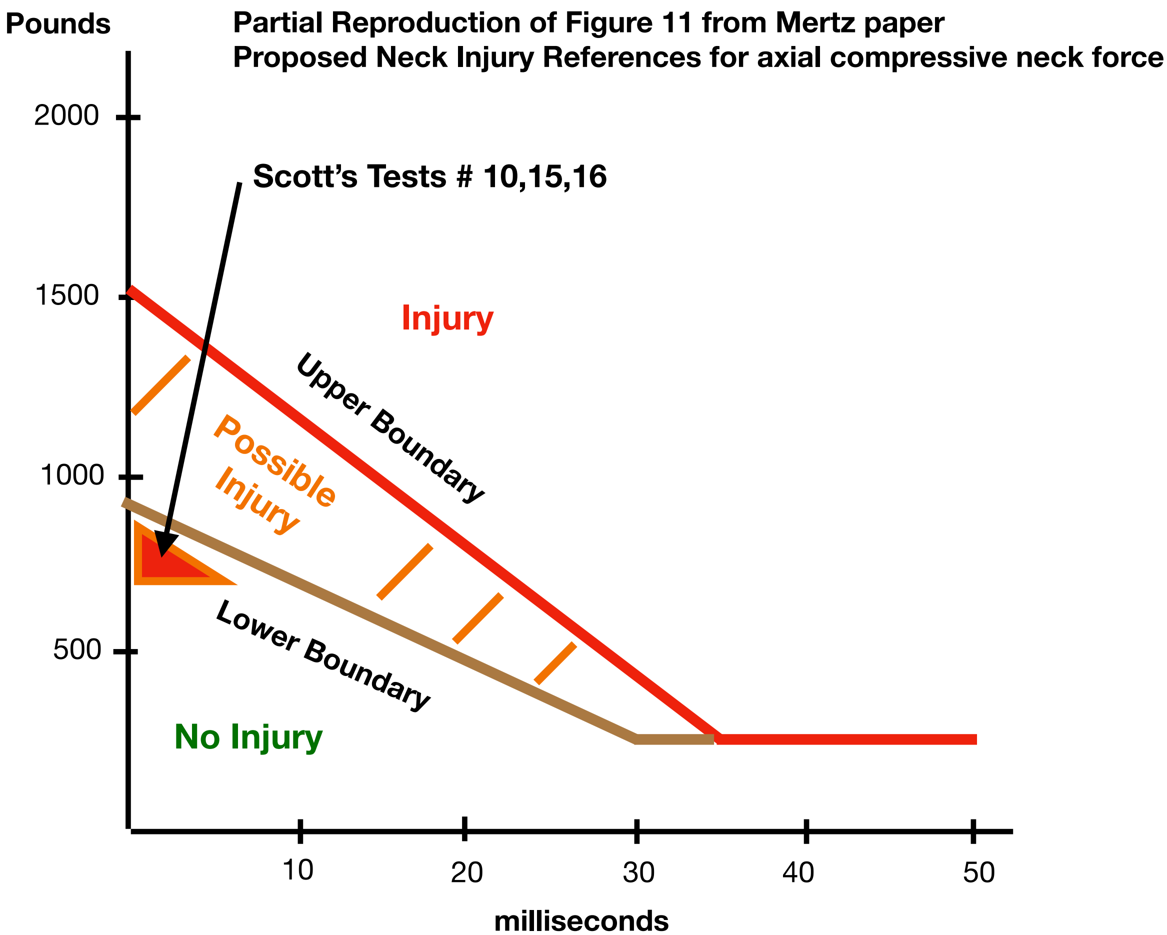

Chart 2: Mertz Axial Compressive Neck Force Boundaries
Scott's Tests # 10, 15, 16 overlaid

Scott says Mertz's *"neck injury criterion is a function of the duration and the magnitude of the compressive load."*

On page 21 of the SAFE Journal version (version 4) of Scott's paper, Scott wrote his:

> *"Tests #10, 15, and 16 would produce compressive loads that come close to injury levels but do not exceed this criterion. Based on this criterion there is a high probability of a severe neck compression injury for head impacts in Position A* (center of forehead) *at impact speeds greater than 15.7 mph* (which he did not test) *and for head impacts in Position B* (along the guard centerline 3.5 inches lower than center of forehead) *at impact speeds greater than 10.4 mph* (which he did not test)*."*

See red area in **Chart 2** for results of tests 10,15,16.

Mertz

Let us backup and talk about what Mertz did. Over a decade before Scott's head impact work, Mertz took minimal data available on three football spring loaded tackle dummy accidents from a source 3 years before his work.

Mertz tried to replicate the accidents using a Hybrid III dummy and recorded the resulting axial neck forces. He and his associates drew a chart showing 3 bands (no injury, possible injury, injury) based on axial force and duration of that axial force as measured by a Hybrid III dummy.

Hybrid III dummies were which known for not being biofidelic when the neck is in compression

Mertz's data represented Hybrid III dummy output when strapped down to a pallet with its head hanging off the end, not human output during impact with a tackle dummy.

Mertz laid great groundwork for others to follow, but his group's research was only based on 3 accidents of which little was known.

Correlation of Mertz's upper and lower bounds derived from just three sketchy accident reports to underwater testing in an entirely different configuration (sitting upright), struck in forehead creating multi-axis forces, while not wearing a helmet are not likely to be very high.

Scott

Now Back to Scott's data. The impacts were quite sharp at speeds over 10 mph (peak neck compression forces only lasting about one to five milliseconds.

Peak axial neck force measure by Scott and his associates in:

1. Test #10 (centered impact, 15.7 mph) - 822 pounds
2. Test #15 (centered a little lower on the guard at 10.4 mph) - 755 pounds
3. Test #16 (centered a little lower on the guard at 10.4 mph) - 851 pounds

Results of the three tests above are overlaid on Mertz's upper and lower bounds in **Chart 2**.

Before we place lots of confidence in the relative location of Scott's Tests #10,15,&16 on **Chart 2**, Mertz and his associates closed their paper with:

> *"Because of the limited information relating neck loadings measured with the GM Hybrid III dummy to known human neck injuries, these injury references should be used only as guides in interpreting data obtained with the dummy. Neck injuries that might result from bending, shearing, axial tension, or combinations of these loadings are not applicable to either of these axial compressive force references."*

Plus, as seen in the next section, the spring in the neck of Hybrid III dummies is several times stiffer in compression than the human neck. Thus greater forces in compressing it than would be in a human neck.

Our Quick Biofidelity Investigation

Neck Stiffness

Don Kueny, former Chief Engineer, and President of OMC testified in the 2009 Decker trial[13]

As reported in the Naple Daily News, Mikal Watts, an attorney for Decker, questioned Kueny about biofidelity of the Hybrid III crash dummy neck. See **Figure 6.**

The same interchange about the dummy is played out in the trial transcript in **Figure 7**.

Kueny knew the dummy's neck was four to five times stiffer than a human's neck, but they used it anyway.

Kueny said, they just used the dummy that was available, "it's what the automobile (industry) used." See **Figure 7.**

Kueny failed to note the automobile industry used the Hybrid III dummy in frontal collisions where the dummy's head rotates forward and down when the car quickly decelerates or was at rest and then struck from the front. The auto industry was not impacting the Hybrid III head with something to get it moving. They just wanted to see the effect of quick deceleration of the car on the dummy's head and seat belt / harness system. The spring in the crash dummy's neck worked fine for their needs. They were not compressing the head downward, knocking it backwards, or knocking it side to side. Deceleration caused the head to move, not striking it with a propeller guard.

OMC knew the dummy's neck resulted in much greater head impact forces than a human neck, but they proceeded anyway. It is obvious that if things had been the other way around, OMC would not have proceeded with the neck generating only a fraction of real world forces. They wanted the propeller guard to fail, not pass. As it is, they have good data for a Hybrid III crash dummy being struck underwater by a propeller guard, but no data for humans being similarly struck.

Kueny went on and tried defending tying the dummy down.

When Don Kueny was asked about **litigation testing** (testing alternative designs proposed by plaintiffs) like they were doing at SUNY, he agreed somebody could conduct testing with the goal of what they wanted to prove, and fix the test apparatus so they got the outcome they wanted. See **Figure 8**.

---

[13] Decker v. OMC and Boston Whaler. Collier Circuit Court. Collier County Florida. Filed May 16, 2002. Concerning death of Audrey Decker by propeller strike.

Boat accident trial: Engineer admits Coast Guard recommend prop guards

Aisling Swift. Naples Daily News June 11, 2009

Decker's attorneys also showed that OMC stopped researching the guards after experiments using crash test dummies. Her attorneys contended that the industrywide tests conducted at the State University of New York at Buffalo were designed to defend boat manufacturers against lawsuits. Manufacturers divvied up the costs of the tests based on a percentage calculated by the number of propeller-injury lawsuits they faced.

"You guys took anthropomorphic dummies, strapped them in and ... basically take a two-by-four and slammed them in the head?" asked attorney Mikal Watts of Texas.

"Yes," Kueny replied.

"Did you know that people who use the anthropomorphic dummies will tell you the stiffness of the neck is four or five times greater than a human's?" Watts asked.

"I have heard that," Kueny said. "... That is true, but it was the best that was available 10 or 15 years ago. It's what the auto industry used."

But Watts pointed out that OMC used the dummies well after that and then abandoned testing of guards.

"You continued to use the dummies so you would get a result that would be four or five times higher than it would be," Watts said, suggesting the tests were designed to get the answer they sought ? proof that guards were dangerous.

It wasn't a question, but Kueny maintained that OMC didn't have the money to create a different dummy.

In his deposition, Kueny testified the tests were designed to show guards caused head injuries, but he backed off that in court.

"I probably could have worded it better," Kueny admitted, adding that tests were designed to prove the assumption right or wrong.

Figure 6: Kueny Testimony in Decker case.
Naples Daily News. June 11, 2009

Audrey Decker & Fred Decker vs. OMC.
Don Kueny trial testimony: Dummy Biofidelilty
Transcript June 11. 2009 Volume 7.

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Q Do you know what a hybrid three anthropomorphic dummy is?

A Yes. Generally.

Q Do you know the people that use the hybrid three anthropomorphic test dummy tell you stiffness of the neck is four or five times greater than that of a human body.

A Heard that.

Q One of the limitations of the dummy, correct?

A Correct.

Q As to whether it is a dummy with bio-fidelity, you heard the hybrid three dummy does not have bio-fidelity in this area because of that stiffness difference between our neck and the four or five times stiffer neck of the anthropomorphic dummy, right?

A That is true but it was the best available 15 years ago and it's what the automobile used. We in a small industry couldn't develop our own dummy to overcome limitations the automotive crash people acknowledged and were not able to overcome.

Q Let's talk about that. You can choose to use a dummy knowing the bio-fidelity is not there so you will get a result four or five times higher than

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it ought to be?

A You can use the dummy available, you can use the best the crash test people in the country have or you can go off on your own and try invent the wheel is what I would call it.

Figure 7: Don Kueny testimony in Decker case
Page 876 & 877

Audrey Decker & Fred Decker vs. OMC.
Don Kueny trial testimony: Litigation Testing
Transcript June 11. 2009 Volume 7.

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it ought to be?
A You can use the dummy available, you can use the best the crash test people in the country have or you can go off on your own and try invent the wheel is what I would call it.
Q Sure. You've never seen an automotive test where you see automotive engineers tie a dummy down and fix it into position so it cannot move. They put them in cars and allow them to rebound off things like air bags and respond to things like seat belts?
A For one thing, they're working in air. We're working in water. Talked about virtual mass, it's a huge difference.
Q Sure. So would you agree with me that if somebody conducts litigation testing with the preexisting goal of what they want to prove that you can fix the test apparatus in whatever way necessary to prove exactly what you want to prove so you can share it with the jury?
A That could be done.

Figure 8: Don Kueny testimony in Decker case
Page 877

Biofidelity Continued

A National Highway Transportation Safety Association (NHTSA) paper[14] on biofidelity of the Hybrid III dummy in automobile rollover accidents concluded:

> *"Previous studies have used the Hybrid-III neck to draw the conclusion that in rollovers, roof strength is not casual (sic, causal) to neck injury. Injury rates occurring in these rollover tests were **two orders of magnitude more frequent** than that seen in real world accidents. This can be directly attributed to the lack of biofidelity of the Hybrid-III neck, and its tendency to over-represent axial compression injuries."*
> **The Hybrid III dummy predicted over 100 times more injuries than seen in real life.**

We noticed no mention of temperature sensitivity in Scott's head impact report. With the crash dummy being in water, temperature can be a biofidelity issue.

> *"Temperature effects should not be overlooked because they influence neck compressive stiffness considerably."*[15]

Drone Biofidelity Testing

Back in 2017 we covered a Virginia Tech research project[16] impacting human heads with drones and noted how this project mirrored underwater head and leg impact studies performed at SUNY years earlier.

Similar research performed in the Netherlands is now available online.[17] They compared drone impacts with a 50 percent Hybrid III male crash dummy with simulated impacts using the MADYMO software package which has been validated against cadavers.

Their Figures 3, 4, and 5 show relative motions of a Hybrid III head compared to a MADYMO model for various impact directions and orientations. Impacts with vertical components (striking from an angle above horizontal) results in human necks (MADYMO model) deforming more than the Hybrid III in the vertical direction. Human necks deform more because the dummy's neck is stiffer.

> *"This shows an effect of the Hybrid III neck system compared to the human body neck system. **Trajectory comparison shows the human head travels further down and over a longer period of time while the Hybrid III head vertical displacement is small and with a faster rebound.** In addition, the human head also rotates in extension direction (chin*

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[14] Fidelity of Anthropometric Test Dummy Necks in Rollover Accidents. Brian Herbst, Stephen Forrest, David Chng. Published by National Highway Safety Transportation Administration (NHTSA). Pages 2093-2097.

[15] Time and Temperature sensitivity of the Hybrid III neck. Schmidt Ortiz-Paparoni, Shridarani, Nightingale and Bass, Traffic Injury Prevention. 2018, Vol,19. No,6, Pages 657-663.

[16] Virginia Tech drone impact tests; dejavu boat propeller guard tests. Gary Polson. PropellerSafety.com. January 21, 2017.
https://www.propellersafety.com/12625/test-propeller-guards/virginia-tech-drone-impact-tests-dejavu-boat-propeller-guard-tests/

[17] Modeling Head Injury due to Unmanned Aircraft Systems Collision: Crash Dummy vs Human Body. Rattanagraikanakorn, Schuurman, Gransden, Happee, Wagter, Sharpanskykh, and Blom. International Journal of Crashworthiness 2020 Ahead of Print.Taylor & Francis.

> *tucks in toward your neck as head rotates forward) when full vertical neck compression is reached, while such rotation is minimal in the Hybrid III head."*
>
> *"For impact cases where theta = 45 degrees (elevated impact) significant differences in head CG acceleration can be observed. …"*
> This corresponds to centered propeller guard strikes where the slope of the leading edge of the guard tries to shove the head down.

Conclusions of the Netherlands drone impact paper
UAS = Unmanned Aircraft Systems

> *"… the Hybrid III dummy has **serious limitations for horizontal UAS impact from side direction and vertical UAS drops as well as elevated UAS impacts**."*

Biofidelity of Face & Skin

Authors of the propeller guard head impact study fail to cite a 1988 Society of Automobile Engineers (SAE) article titled, Facial Impact Response - A Comparison of the Hybrid III Dummy and Human Cadaver.[18] Conclusions of the SAE paper are in **Figure 9**.

Scott's paper notes observing a strange phenomenon during the center strikes. The neck is in both flexion and compression at the same time by the lower part of the neck sliding to the rear while the upper part begins to bring the chin downward toward the chest. See our **Figure 10** and the explanation below.

> quote from page 18, *"A surprising finding in the centered tests was the flexion moment that was developed in the upper neck during the Phase 1 impact. While the flexion moment was not large enough to produce an injury (325 in. lbs in Test #10), the presence of this moment demonstrates how the guard interaction with soft tissues **may** generate biomechanical forces away from the point of impact. The schematics in Figure 6* (our **Figure 10**) *demonstrate how this flexion moment is **thought to occur**.*
>
> *Initially the impact causes the upper neck to translate reward with the base of the skull, while the base of the neck remains relatively stationary. As the head moves rearward the neck wants to go into extension but the guard, which has penetrated into the rubber skin, prevents the head from rotating into extension. This places the neck in an unusual situation since it must maintain the connection between the rearward moving, not-rotating head and the stationary torso. The neck **appears** to accommodate the head and torso by having the upper neck go into flexion and the lower neck go into extension. Once the head is free of the guard, Phase II, the restraining force can no longer be applied and the head rapidly goes into extension."*

---

[18] Facial Impact Response - A Comparison of the Hybrid III Dummy and Human Cadaver. Douglas Allsop, Charles Warner, Milton Wille, Dennis Schneider, Alan Nahum. SAE paper #881719. 17 pages.

Facial Impact Response - A Comparison of the Hybrid III Dummy and Human Cadaver

Allsop, Warner, Wille, Schneider, and Nahum

SAE Paper #881719

Even though there is a significant amount of scatter in the stiffness data for the zygomatic and maxillary regions of the human cadaver, the Hybrid III dummy face is at least three times stiffer than any cadaver head tested. This undoubtedly results in dummy-crash-test accelerations and forces that are artificially high, making correlation with biomedical research found in the literature nearly impossible. As observed in this test series, the midface impacts on the Hybrid III face resulted in forces of approximately 10,000 newtons, while the cadaver impacts averaged about 2000 newtons, and never exceed 3,500 newtons on any impact.

CONCLUSIONS

While recognizing the limitations of the small sample size employed in this research, the following conclusions and recommendations are indicated:

1) Average stiffness values for the human cadaver head in the frontal, zygomatic, and maxillary regions are approximately 1000, 150, and 120 newtons per millimeter respectively.

2) The Hybrid III face is several times stiffer in the midface region and should be redesigned if it is to yield accurate facial impact force and acceleration readings when used as an evaluation tool in automobile design.

3) Additional research is recommended to expand the sample base so that the quantitative conclusions listed can be refined.

Figure 9: Hybrid III Facial Impact Response

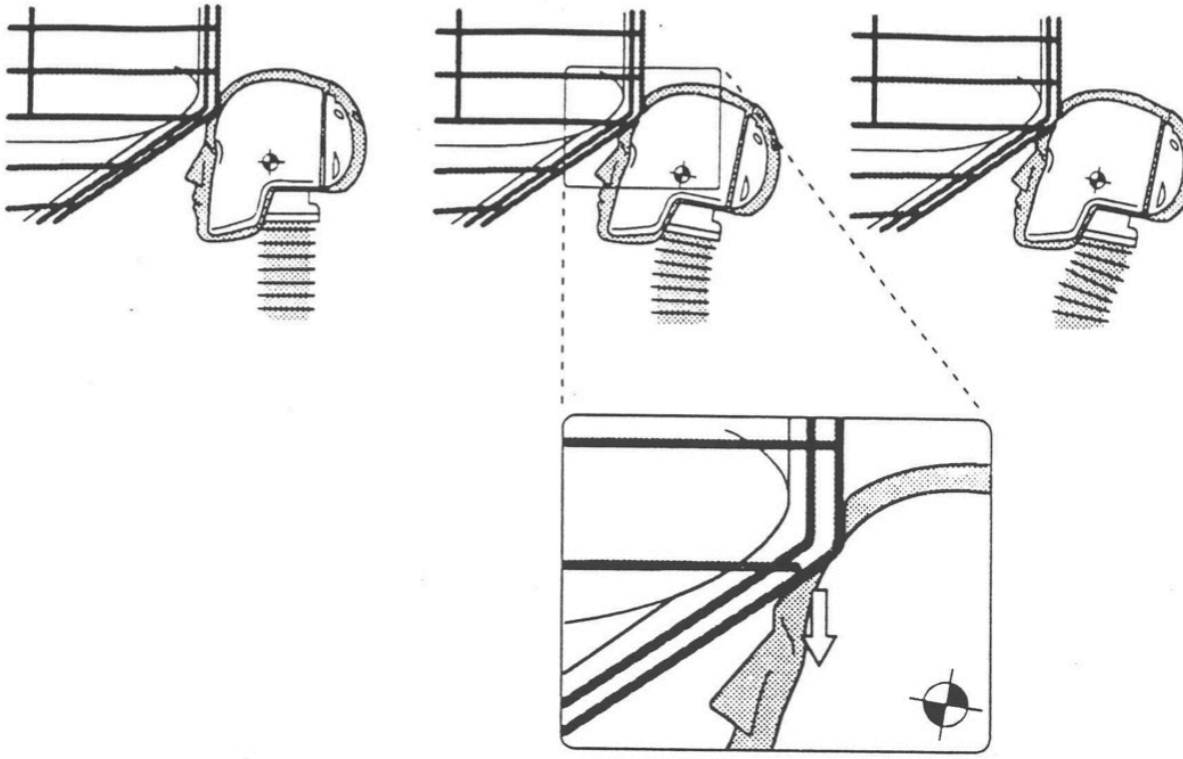

Figure 6. Guard Engagement with the Rubber Skin on the Forehead of the ATD in the Centered Impact. Arrow in the Blow-Up is the Downward Reaction Force Applied to the Head that Prevents the Head From Rotating.

Figure 10: Neck in extension and compression at the same time
Figure 6 from SAFE Journal version

Neck Simulation Needs to Be Improved

A 1997 American Society Testing and Materials (now ASTM International) article,[19] discusses the need for a more biofidelic neck than the Hybrid III crash dummy, and problems of the Hybrid III neck. See **Figure 11** and **Figure 12**.

Their article references a 1996 version of the article published by ASTM in “Safety in American Football”.

As you read the article, note, cervical refers to the neck vertebra.

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[19] Enhancing Safety with and Improved Cervical Test Device. Kleinberger, Eppinger, Haffner, and Beebe. ASTM Proceedings. 1997.

Michael Kleinberger,[1] *Rolf Eppinger,*[2] *Mark Haffner,*[1]
and Michael Beebe[3]

Enhancing Safety with an Improved Cervical Test Device

REFERENCE: Kleinberger, M., Eppinger, R., Haffner, M., and Beebe, M., **"Enhancing Safety with an Improved Cervical Test Device,"** *Safety in American Football, ASTM STP 1305,* Earl F. Hoerner, Ed., American Society for Testing and Materials, 1996, pp. 60–74.

ABSTRACT: The cervical spine serves two primary functions: (1) as a mechanical linkage that allows a large controlled range of head motions and (2) as a protective structure for the spinal cord that passes through the spinal canals of the vertebrae. Cervical injuries involving fracture or dislocation of the vertebrae often involve the spinal cord, leading to paralysis or even death. Although serious neck injuries have become relatively rare in American football since the adoption of new spearing rules and tackling procedures, the development of cervical protective equipment should further reduce both the severity and the frequency of neck injuries.

Many developers of cervical protective devices use anthropomorphic test devices, or ATDs, as physical surrogates for the athlete. Currently available ATDs are of limited biofidelity and ability to predict neck injuries under conditions involving head impact. This paper discusses the ongoing development of a new cervical test device with improved biofidelity in the frontal, lateral, and axial directions. A new transducer is proposed to measure dynamically the three-dimensional curvature along the length of the neck.

KEYWORDS: anthropometric test devices (ATDs), neck injury, cervical spine, injury criteria, finite element analysis

Introduction

The incidence of neck injuries in motor vehicle crashes totals in the hundreds of thousands every year. In 1993 alone, an estimated 340 000 cervical spine injuries occurred, which breaks down to approximately one injury every 1.5 min. If we consider only the more serious injuries (Abbreviated Injury Scale (AIS) > = 3), the occurrence drops down to around 9170 injuries; this is still orders of magnitude higher than the incidence of neck injuries in football. One factor that accounts for this difference is the number of participants in each activity. In 1993 there were over 175 million licensed drivers in 1993, compared with approximately 1.8 million participants in American football. Another factor is the higher energy levels associated with automotive crashes. Whether the injuries are sustained in the automotive or athletic environments, the human neck remains the injured structure. For this reason, the large amount of

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Figure 11: ASTM article, first page

research conducted for automotive or other types of crashes can be applied to the study of football injuries.

Athletic performance and typical human responses to various input conditions are routinely investigated using volunteers. Volunteer testing is limited, however, to noninjurious loading. To extend our knowledge into the realm of injury mechanisms and tolerances requires the use of a human surrogate. Surrogates can take many different forms, such as cadavers, animals, or a physical approximation to the human anatomic structure. This latter example includes the anthropomorphic test devices (ATDs or dummies) developed by the automotive and aeronautical research communities. The fact that these devices are durable, repeatable, and easily instrumented makes them a favorable choice for a surrogate.

Extreme care should be taken though when attempting to use these devices to evaluate injury potential under conditions for which they were not designed. An excellent example of this is the dummy neck being used in research to record neck loads during a head impact. The currently used Hybrid III dummy neck was designed to provide proper head rotation during a specified acceleration pulse applied to the base of the neck. This corresponds to a frontal crash in which the inertial loading from the head forces the neck into flexion without any head contact. The biofidelity of the dummy neck rapidly deteriorates once head impact occurs. This is largely due to the fact that the Hybrid III neck is too stiff when loaded in the axial direction compared with data from human cadaver tests. Another discrepancy between the Hybrid III and human necks is that the dummy neck does not allow any free rotation of the head relative to the neck. For these reasons, great care has to be taken when evaluating injury susceptibility based on experimental tests performed with currently available ATDs.

One solution to the problem is to design new ATDs which are more biofidelic in a wide variety of impact loading conditions. An exact replica of the human anatomic structure will probably never be created, but there is certainly room for improvement over current designs. The National Highway Traffic Safety Administration (NHTSA) is currently working on improvements to almost every component of the dummy anatomy. This paper will discuss the development of a new dummy neck with improved biofidelity in frontal flexion, lateral bending, and axial compression. Axial biofidelity is extremely important because serious cervical spine injuries often result from compressive loads directed through the cervical column.

Performance Specifications

The new cervical test device under development is primarily intended for use in frontal crash investigations. However, it is hoped that the same neck will be suitable for crash studies in all directions, including cases in which head impacts occur. A document entitled "Performance Criteria for a Biofidelic Dummy Neck" [*1*] was written to specify detailed requirements for neck biofidelity in all directions. This report attempts to compile all available neck response data to provide a set of criteria with which to judge a proposed dummy neck. In other words, if someone wishes to determine whether a given neck design is "biofidelic," its responses can be compared with the specifications in this document to judge its biofidelity. Kinematic and kinetic response corridors are provided for flexion-extension, lateral and oblique bending, axial compression-tension, and torsion.

Kinematic performance specifications are based largely on volunteer tests conducted at the Naval Biodynamics Laboratory (NBDL) by Ewing et al. [*2–7*] and analyzed by Wismans and Spenny et al. [*8–13*]. These data include translations and rotations of the head/neck complex during low velocity sled tests conducted in the frontal, lateral, and oblique directions. Plots are presented for neck angle (theta) and head angle (phi) versus time, as well as neck angle (theta) versus head angle (phi). Definitions of these angles are given in Fig. 1. Theta-phi plots indicate that the head rotation lags somewhat behind the neck rotation in a frontal crash.

Figure 12: ASTM article, second page

BioRID-2

The Hybrid III crash dummy was created to simulate humans in frontal automotive impact (car struck from the front), and especially humans using some sort of restraints (seat belts, chest straps, airbags, etc). The head can rotate forward like it does in a head on collision and reasonably replicates human response.

BioRID[20] and BioRID2 crash dummies came along later to simulate rear impact collisions, where the neck bends backwards like it did in the SUNY testing. Construction of BioRID necks mimics that of a human neck instead of just using a spring like Hybrid III.

Sliding Head / Lubrication

A 1996 SAE article[21] investigated sliding of the Hybrid III head against a flat metal plate and the impact of lubrication such as a protective chamois on the head or use of chalk or water. In forehead impact drop tests, a wet headed dummy slides on a metal plate decreasing its angular acceleration.

Designing a propeller guard to maximize sliding might be a good feature to evaluate. Sliding might trade head injuries for neck injuries. See **Figure 13**.

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[20] Designed in 1999 in Sweden.

[21] Variability of Head Injury Criteria with the Hybrid III Dummy. Crandall, Martin, and Pilkey. Society of Automotive Engineers. 960094.

condition 4 is often used by testing agencies to mark head contacts with interior vehicle components. Results are given in Table 2 and indicate a significant drop in HIC due to any friction-reducing substance on the head of the Hybrid III dummy. Figures 4 and 5 are frames from a high speed video of two actual tests at the points of maximum head rotation. The photos illustrate the tremendous increase in head rotation that occurs when the impact surface is slippery.

Similar results were obtained in head drop tests using the calibration stand described in FMVSS 572.32. The test is used to check the calibration of the Hybrid III dummy head prior to compliance testing. To be considered calibrated, the maximum resultant head acceleration produced by a 376 mm drop must fall within 225 to 275 G's. The application of chamois, water, and chalk reduced the maximum resultant acceleration of the head by 26%, 27%, and 9%, respectively.

The presence of a lubricant reduces the effective stiffness of the plate during an impact. It follows that the translational component of acceleration -- and the HIC value -- is also reduced. Moreover, the slick surface allows the head to rotate, thereby decreasing its angular acceleration. However, the greater amount of head rotation brought about by the slippery surface may increase the risk of neck injuries.

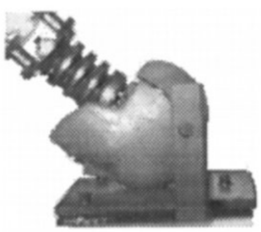

Figure 4. Maximum rotation - dry head and plate.

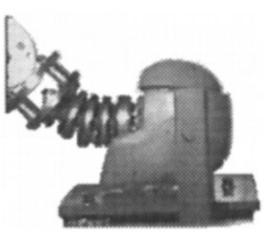

Figure 5. Maximum rotation - wet head and plate.

SIMULATION OF HEAD DROP TESTS

To study the effects of impact location and surface lubrication on head response, a model of the head drop stand was developed for the Articulated Total Body (ATB) occupant simulator. The ATB model is shown in Figure 6.

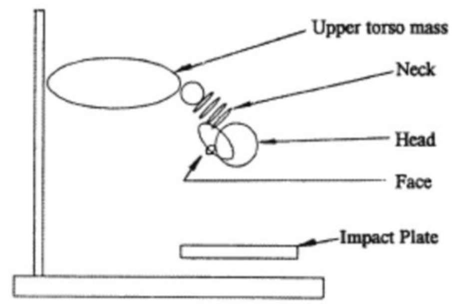

Figure 6. ATB model configured for a forehead impact at a 45° pitch angle.

FOREHEAD IMPACTS - Head impact simulations were run under the same test conditions described earlier -- 61 cm drop height, 45° pitch, and 0° roll -- with two plate surface conditions: dry (high friction) and wet (low friction). The time histories of the rotational head movements are shown in Figure 7.

In the ATB simulation of the high friction case, the head initially pitched forward (negative rotation) by a small amount because the high frictional force did not allow it to slide along the plate. This behavior was also exhibited in the high speed video of the actual test. The maximum "dry" head rotation in the ATB model, shown in Figure 7, was only 25°, while the actual "dry" Hybrid III head shown in Figure 4 experienced even less rotation.

In the simulated low friction case, frictional forces were low enough to allow the head to slide forward as soon as it made contact with the plate. As it slid, the head pitched backwards (positive rotation). The maximum head "wet" rotation of 37° in the ATB model seen in Figure 7 was much greater than rotation in the high friction ATB model. Moreover, the actual "wet" Hybrid III head shown in Figure 5 had even more rotation.

Figure 13: SAE Hybrid III Crash Dummy Head Lubrication Paper
Variability of Head Injury Criteria with the Hybrid III Dummy
Crandall, Martin, and Pilkey
SAE Paper # 960094

Many more technical articles point out the Hybrid III dummy's neck compression problem. This one by Friedman[22] was presented at the 2001 American Society of Mechanical Engineers (ASME) International Mechanical Engineering Congress and Exposition. See **Figure 14**.

IMECE2001/BED-23100

COMPARISON OF UPPER AND LOWER HYBRID III DUMMY NECK COMPRESSION FORCES UNDER VERTICAL LOADING

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INTRODUCTION

The determination of the relationship of the upper and lower Hybrid III dummy neck transducer loads during vertical drop test loading was of interest in the present study. The anthropometric test device is a tool used in crash analysis. It is typically used for frontal or side crash analysis. It has however been used for vertical drop or rollover studies (1).

The Hybrid III dummy neck is not representative of the human neck in compression; for example, the Hybrid III neck is at least 10 to 20 times stiffer than the human neck (2,3). Experiments have been conducted with whole body cadavers with the head and body aligned with a special apparatus to keep the structures vertical. Under such conditions clinical fractures do not occur in the human neck until the cadaver is dropped in the region of 1.2 to 1.5 meters onto its head (4). Similar results have been found by others (5).

In experiments examining the ability of the neck to transmit loads, it has been found that the Hybrid III neck will transmit approximately 75 to 80 percent of the load applied to the head to a load cell at the torso end of the neck. In the human neck only 25-30 percent of the load will be transmitted (6). These tests were done at rates of about 4 to 6 m/s with the head and neck tested.

Inverted vertical drop tests with the Hybrid III dummy onto a vehicle roof resulted in upper neck load cell results of approximately 10,500 N at a .5 m drop height and 4,000 N at a .05 m drop. However, lower neck transducer loads were not obtained (7).

Interpretation of the compression values obtained from use of the Hybrid III dummy neck were derived from football related experiments. The Hybrid III dummy was strapped onto a moveable pallet. The speeds that were chosen to represent injury were studies in the region of 3 m/s for the head contact with forces of about 4,000 N. In contrast, the football players had neck injuries at head butting contact speeds over 9 m/s. In live human to parallel Hybrid III dummy neck studies, a 0.9 m drop gave a value for the human of 1,500 N (1).

METHODS

A Hybrid III 50% dummy manufactured by Utama Engineering was instrumented with upper and lower neck load cells. The upper load cell was a Denton 1716A load cell while the lower load cell was a Denton 1794A load cell. A strip switch was attached to the top of the head to determine the initial contact time. In Series 2 a head, chest and pelvis triaxial accelerometers was used. Data was collected using a Diversified Technical Systems, Inc. TDAS Pro data acquisition system in conjunction with a Toshiba Satellite PA1240U VCD laptop computer. A sampling rate of 10,000 Hz was used for all channels. The data from the neck transducers was reduced after filtering at SAE Class 600. In Series 2, two high speed black and white video cameras (Kodak SR 1000 and Kodak SR 500) were used viewing the impact from the front and left side at 500 fps each.

To position the dummy, a nylon web strap was positioned around the pelvis of the dummy and attached to a release shackle. A release shackle was connected via chain to a block lift. The sitting dummy was lifted and put in an inverted position with the dummy's neck aligned to be perpendicular to the contact surface. The lift was then adjusted to position the dummy with selected clearances between the head and the contact surface.

In Series 1, the 50% Hybrid III dummy was weighted to 91 kg; the additional weight was attached at the arms and legs. In this series the contact surface was 1.5 cm thick plywood over concrete. Drop heights of 6.08 m, .10 m, .15 m and 0.20 m were used. In series 2, drop heights up to 0.4 m were used with a 76 kg dummy.

RESULTS

The dummy upper and lower neck vertical loads differ by about 20 to 25 percent for both the 91 kg or 76 kg dummy tests. The maximum value of about 10,000 N was recorded at the upper neck transducer at the 0.4 m drop height. The corresponding vertical neck loads versus head contact velocity are given in Figures 1 and 2 for the 91 kg and 76 kg dummy, respectively. The peak force was rapidly increased with drop height.

1

Copyright © 2001 by ASME

Figure 14: ASME article

[22] Comparison of Upper and Lower Hybrid III Dummy Neck Compression Forces Under Vertical Loading. Keith Friedman, Friedman Research. 2001 ASME International Mechanical Engineering Congress and Exhibition. November 11-16, 2001. New York, New York. IMECE2001/BED-23100.

Summing up Biofidelity

The Hybrid III dummy's **neck spring is several times too strong** in the vertical direction to represent cadaver necks, or human necks. Countless technical papers have pointed out this issue. We identified a few of from different organizations on previous pages, including:

1. NHTSA - National Highway Traffic Safety Administration
2. ASTM - American Society Testing and Materials (now ASTM International)
3. ASME - American Society of Mechanical Engineers
4. The International Journal of Crashworthiness

Scott recognized the stiff neck issue in the Preliminary Report version of the head impact paper. His comments were removed by the final draft.

Don Kueny, then Chief Engineer at Outboard Marine Corporation, testified of their knowledge about the neck stiffness issue.

Not only the neck had biofidelity issues, the face was too stiff per an SAE paper, and the skin was not designed for impact.

The Hybrid III dummy was created for studying the body's response in frontal car crashes. Its neck does not replicate side of the head impact performance of human necks.

The underwater head impact study applied vertical and side impact forces to the neck which was not designed to replicate human necks. The head impact study performed 17 impacts all of which were influenced by biofidelity issues listed above.

Combine that with the "**may**", "**thought to occur**", and "**appears**" they used in discussion of **their Figure 6** (**our Figure 10**) and it is apparent their findings would need to be confirmed by another study using cadavers or a proven biofidelic crash dummy. See our **Biofidelity of Face and Skin** section.

Researchers at SUNY used a human computer model to simulate the 17 impacts. The simulation was reasonably consistent with their findings but the simulation was based on Hybrid III anatomical data, not on human or cadaver data.

Some studies like the SUNY study (reaching out beyond areas previously studied using Hybrid III dummies), begin by verifying the crash dummy's performance in this new situation by testing one of more cadavers to make sure the Hybrid III is replicating human performance. That was not done in this instance.

A more biofidelic neck might have an entirely different mode (skin might not tear, skin might not resist sliding as much, neck could be bending in a different mode) and forces could be drastically different with a modern more biofidelic face and neck.

The only mention of biofidelic issues in the final version of the paper is the guard sticking against the dummy's skin.

Biofidelity issues with the Hybrid III neck were known at the time of the SUNY testing as shown by Scott mentioning them in his preliminary report. Since then, many technical papers such as those in **Figures 11,12,13,&14** have brought much more information to light. If Mercury Marine still wants to stand on these tests, they should rerun them with a crash dummy with biofidelity in the manner in which it would be impacted, and verify the results with cadavers.

Ten Biofidelity Firsts Without Cadaver Verification

The literature is filled with examples of researchers doing something not previously attempted with a Hybrid III crash dummy, verifying their results with a cadaver(s). Then running more tests with things a little heavier, smaller, faster, slower, at a different angle, etc with the dummy.

In the instance of this underwater head impact paper, there were many firsts or points to be verified including:

1. Testing underwater may cause unanticipated changes in performance or readouts
2. Their plan for handling Added Mass may not truly represent what is going on
3. Striking the forehead then trying to ride over the head while pushing it down
4. Neck stiffness changes due to water temperature
5. Slickness of water on the head and guard may introduce changes in performance or readouts
6. Ripping skin and sliding metal on metal
7. Sticking characteristics of Hybrid III skin may not represent human skin
8. Sliding along the side of the guard introduces side forces to the head the Hybrid III dummy was not designed to take
9. The Hybrid III Face is multiple times stiffer than a human face
10. Dummy head, neck, and chest were inflated with compressed air to spot leaks - may make them stiffer and change performance

While Scott's underwater propeller guard head impact study has lots of problems, it is commendable that the researchers plowed so much new ground and identified some of the issues above themselves.

I have some knowledge of crash dummies but am far from being an expert. Nonetheless, It seems obvious that introducing the 10 changes above (and maybe more) in conjunction with knowledge of the axial neck stiffness issue would require cadaver verification of their data.

It is likely cadaver verification would have to take place in steps to find the problems, as it is almost certain that more than one of the ten items listed above are likely to create biofidelity issues, especially when they are combined with each other and with known axial neck stiffness issues.

While it would still be challenging to duplicate the author's work, it would be easier to follow in BRC and Scott's footsteps, than to blaze that trail the first time.

Scott, Guzman, Benedict, & Raddin on Biofidelity

Michael Scott, Herbert Guzman, and James Benedict were listed among the authors of the underwater propeller guard head impact study. James Raddin was listed in other references to the propeller guard study.

All the above are listed as coauthors of a 1993 study[23] comparing human and dummy head kinematics during automobile low speed rear impacts as well as other Biodynamic Research Corporation personnel. See **Figure 15**.

In 1993, whiplash was a major issue. Originally researchers thought it was due to human necks extending beyond physiological limits (head swinging too far). However, as more vehicles began to have head restraints it became apparent head restraints were not the answer. Head restraints helped some, but whiplash from low speed rear-end collisions was still a major problem.

They still needed to identify "the injury mechanism or mechanisms that cause the whiplash injury."

Biodynamic Research Corporation undertook a study in vehicle behavior and occupant kinematics in low speed rear-end impacts.

Stated purposes of their study were to:

1. Obtain preliminary information on the kinematics of the human head and neck in low-speed rear-end impacts.

2. Compare the Hybrid III 's head and neck motion with the human's motion.

They had the same live human, 50 year old male driving each of four different vehicles, with the same crash dummy in the passenger's seat each time.

The crash dummy was 50 percent male Hybrid III dummy (same model as in the earlier underwater testing for Mercury and OMC).

A vehicle was struck from behind at different speeds by another vehicle known as the bullet vehicle. The bullet vehicle was rolled down a ramp in order to reach the desired impact speed.

Rear-end impact speeds were 2.4, 4.1, and 4.9 miles per hour.

A series of ten crashes were conducted, but only three are written up in this paper (one at each speed).

NOTE - SUNY underwater propeller guard impact testing had many similarities to slow rear-end automobile impacts. The person struck was seated, head initially rotates backwards, collisions speeds overlapped this speed range, same model Hybrid III crash dummy was used, collisions were filmed with high speed cameras, dummies were instrumented, etc.

---

[23] Comparison of Human and ATD Head Kinematics During Low-Speed Rearend Impacts. Scott, McConnell, Guzman, Benedict, Raddin, and Hatsell. Biodynamics Research Corporation. SAE International Congress and Exhibition. Detroit Michigan. March 1-5, 1993.SAE Technical Paper Series. 930094.

SAE TECHNICAL
PAPER SERIES

930094

Comparison of Human and ATD Head Kinematics During Low-Speed Rearend Impacts

Michael W. Scott, Whitman E. McConnell, Herbert M. Guzman,
Richard P. Howard, John B. Bomar, Harry L. Smith,
James V. Benedict, James H. Raddin, and Charles P. Hatsell
Biodynamic Research Corp.

CONCLUSION

The motion of the human head and neck appears to be much more complicated than the Hybrid III's head and neck motions in low-speed rearend impacts, not a surprising finding when one considers the more complex anatomical structure of the human head and neck compared to the Hybrid III's. Preliminary results indicate that the Hybrid III would probably not be a good human surrogate for evaluating whiplash injury potential in low-speed rearend impacts with ΔV's in the range of 4.0 kph to 8.0 kph as the ATD's head and neck kinematics are dissimilar to the human's. A final evaluation of the Hybrid III's whiplash injury predicting capabilities cannot be made until the actual injury mechanism or mechanisms of the whiplash injury are better defined and the ΔV range is extended past 8.0 kph.

Reprinted from: Human Surrogates:
Design, Development and Side Impact Protection
(SP-945)

SAE The Engineering Society
For Advancing Mobility
Land Sea Air and Space®
INTERNATIONAL

International Congress and Exposition
Detroit, Michigan
March 1-5, 1993

400 Commonwealth Drive, Warrendale, PA 15096-0001 U.S.A. Tel: (412)776-4841 Fax:(412)776-5760

Figure 15: BRC Rear-end Impact Paper - biofidelity issues

Beyond being underwater, one major difference during propeller guard testing was the dummy's neck being compressed when the guard slid over its head.
Authors in the rear-end car crash testing found crash dummy biofidelity problems to be a major issue in their testing, even without the special issues of underwater testing in the propeller guard testing.

Rear end car crash authors found:

1. Human hips appeared to rise up off the seat allowing the human's torso to "ramp up" / slide up the back of the seat. The dummy did not "ramp up" the seat. Their Pages 7-8.

2. Vertical motion of the human's head was not fully attributable to ramping up the seat. They postulated some of it was due to the human's spine partially straightening during the collision. The dummy's spine did not. Their Page 8.

3. The human neck tends to bend up inside the head. The dummy neck bends lower on the spring. Their Page 6.

4. They attribute vertical motion of the human's neck due to being compressed during the first half of the stage when the head appears to be rotating backwards. Their Page 8.

NOTE - the head does not actually rotate backwards. Inertia of the head keeps it in the same place in space while the car (and seat) quickly push the body forward during a rear-end collision.

The authors state:

"If the whiplash injury mechanism turns out to be related to the forces that generated the forward or vertical translational accelerations, the Hybrid III ATD would appear to be a poor surrogate to evaluate whiplash injury potential in the delta velocity range of 4 to 8 kilometers per hour." Page 8.

They go on to state:

"The Hybrid III also did a poor job of duplicating the rotational motion of the human head."

Their conclusion states:

"The motion of the human head and neck appears to be much more complicated than the Hybrid III's head and neck motions in low speed rearend impacts, not a surprising finding when one considers the more complex anatomical structure of the human neck compared to the Hybrid III's."

Their rear-end impact paper was presented in March 1993 as a reprint of an earlier collection of 16 SAE papers.[24] The collection was also published in 1993.

Even with all the problems mentioned in the rear-end impact paper plus the **Ten Biofidelity Firsts** listed in the previous section, BRC and Scott still submitted their propeller guard impact manuscript to SAFE Journal for review on March 24, 1994 **with no mention of these biofidelity issues**, likely due to industry pressure.

---

[24] Human Surrogates: Design, Development and Side Impact Production. SAE SP-945. 1993.

Sometimes Biofidelity Doesn't Matter: Thibault

Even if the Hybrid III neck was biofidelic it does not mean the data represents real life impacts.

Most propeller head strikes we have observed are to the top or back of the victim's head. Even if you just look at random odds, heads have four sides and a top. Only 20 percent random chance of being struck from the front if struck in the head from only one side.

Biofidelity is meaningless if you are not striking heads in the way they are struck in real life.

Data from early studies[25] and current observations show those struck in the head are more likely to die than those struck elsewhere.

In Thibault's 1987 letter to Bolden,[26] Thibault includes sketches of how 19 victims approached the propeller. Of those 19 accidents, only one, a snorkler standing on bottom in front of the oncoming propeller with his head submerged, is in a configuration somewhat similar to the SUNY test. Per the sketch he went down one side of the outboard motor and would have been a candidate for sliding off the guard vs blunt trauma impact.

Biofidelity does not matter unless you are testing in a manner similar the accidents.

Three additional points not directly related to the dummy that may have impacted the outcome were:

1. No boat was attached to the outboard motor. Boats have considerable influence on the fluid pressures and flows around the motor and propeller guard.

2. The propeller was not powered. The propeller has a great deal to do with flow abound the motor and propeller guard.

3. The motor is constantly circling, not really running in a straight line. It is being drug like it is turning all the time which influences flow around the drive and propeller guard.

---

[25] Steering / Struck-by-Propeller Accident Study 1983 Recreational Boating Accidents. Gary Traub. G-BP-1. December 18, 1984. Page A-5.

[26] Lawrence Thibault letter to Stephen Bolden regarding Thibault's study of propeller guarding, including an analysis of 19 propeller accidents. Is among materials assembled by the 1989 NBSAC study.

Outboard Trim and Tilt

Trim, angle of the outboard, is changed to control attitude of the boat (nose / bow high or nose / bow low plowing though the water). As the boat goes up on on plane (skimming on top of the water) the outboard is normally trimmed out (back and up). This raises the bow, reducing drag.

When the boat is trailered, they are normally tilted up to prevent the propeller or lower end of the drive from impacting something and being damaged. **Figure 16**: Outboard Motor Trim and Tilt was developed from a Yamaha image.

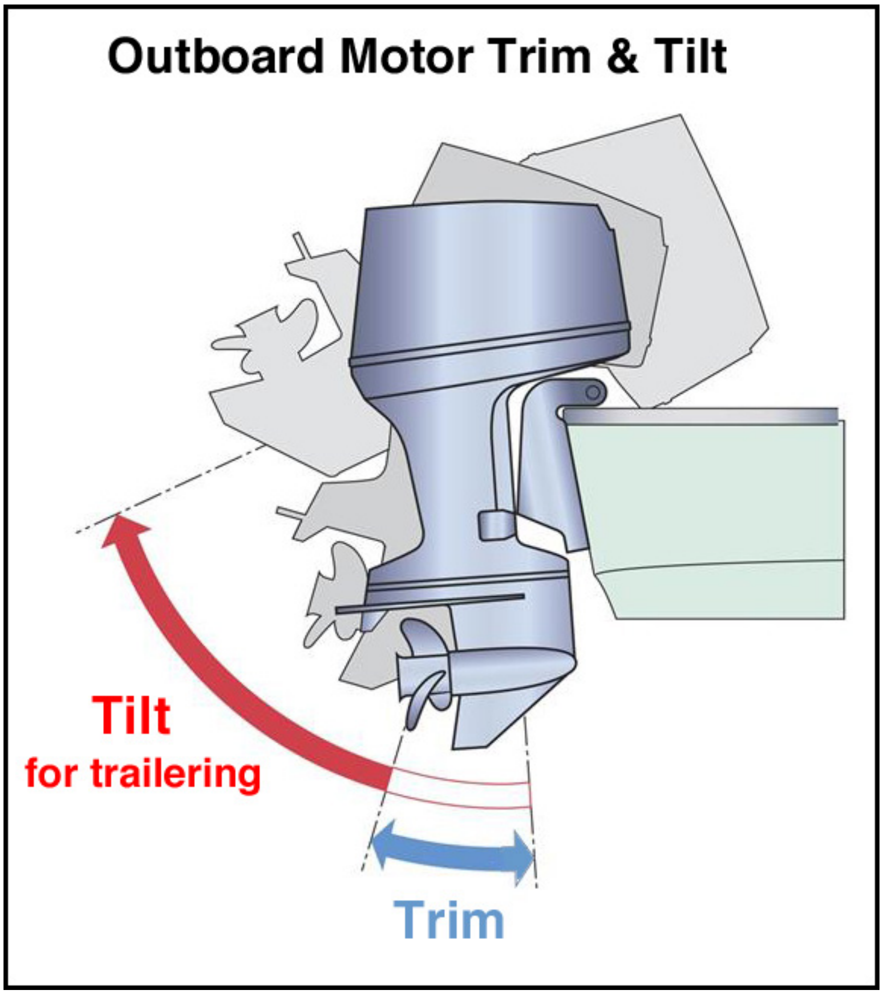

Figure 16: Outboard Motor Trim and Tilt
developed from a Yamaha image

Simulating Propeller Thrust

OMC said propeller thrust for this 115 horsepower outboard motor is about 200 to 320 pounds at the prop shaft.

Tests at SUNY were performed with a large arm swinging the outboard around the circular tank with the outboard motor engine off and the propeller freewheeling (in neutral). The process results in zero propeller thrust which would normally be pushing the drive forward.

If a propeller guard on an outboard motor mounted on a boat in a lake runs into a crash dummy head, the outboard has both kinetic energy due to its mass and speed plus the thrust force of the propeller.

Early plans called for using a spring to simulate propeller force. Basically the outboard would be sprung into the trimmed down position from the structure mounting it above the track (large donut shaped water tank). Instead Don Kueny, OMC Engineering, sent Mike Scott a letter[27] describing a technique in which they could use the trim system to simulate propeller thrust.

Log Strike System

Outboard motors strike floating and submerged debris including logs, rocks, and about anything imaginable in the water. This particular outboard uses a system of relief valves and check valves to allow the outboard motor to tilt up when it strikes something, then slowly back down after it clears the object. For a detailed explanation of a modern version of the process see our “Why Outboards Used in Bass Tournaments Disproportionately Break Off & Flip into Boats Compared to Other Outboard Motors”.[28] Or see actual documents for this outboard’s trim system.[29]

Thrust Rod

A series of holes is provided in the outboard motor mounting structure to receive a thrust rod. This rod extends across in front of the upper end of the leading edge of the outboard, limiting how far down the outboard motor can be trimmed.

Kueny’s Plan

Kueny’s Plan is to set the thrust rod to where the outboard motor can only trim down til the leading edge of the outboard motor is vertical with respect to the ground. He calls for using the electric pump to tilt the outboard down to the pin, then try to push it down further with the hydraulic system which builds up about 800 psi in the rod end of the tilt cylinder. See **Figure 17** and **Figure 18**.

---

[27] Don Kueny, of OMC, letter to Mike Scott, of Biodynamic Research Corp. regarding simulating propeller thrust with the trim system. October 16, 1990. 2 Pages. This letter became the last two pages of Scott’s Preliminary Report.

[28] Why Outboards Used in Bass Tournaments Disproportionately Break Off & Flip into Boats Compared to Other Outboard Motors. Gary Polson. PropellerSafety.com. Pages 57-60. http://www.propellersafety.com/wordpress/wp-content/uploads/bass-outboard-flip-paper.pdf

[29] Johnson Outboard Service Manual. 1973-1991. 60-235 horsepower. 2-stroke. SM-04030. Chapter 9. Trim/Tilt. Striking an Underwater Object. Pages 9-6 and 9-8.

OMC

OUTBOARD MARINE CORPORATION

MARINE

October 16, 1990

Mr. Mike Scott
Biodynamic Research Corp.
9901 IH 10 W
Suite 1000
San Antonio, TX 78229

Dear Mike:

We have discussed further within Engineering how to simulate propeller thrust without interference with normal shock absorber controlled tilting on impact. We have identified what we believe is a simple solution to the problem using the outboard's own power tilt system.

This system, in its "down" mode, loads the outboard in the same direction as prop thrust. When run in the "down" mode to the mechanical stop, the valving maintains 800 psi in the system after the electric motor is turned off. Against the piston of 2 square inches, this provides 1600 pounds of force. Calculated through the appropriate moment arms, this equals about 250 pounds at the propshaft, very close to the 198-321 pound range of estimated thrusts. See sketch.

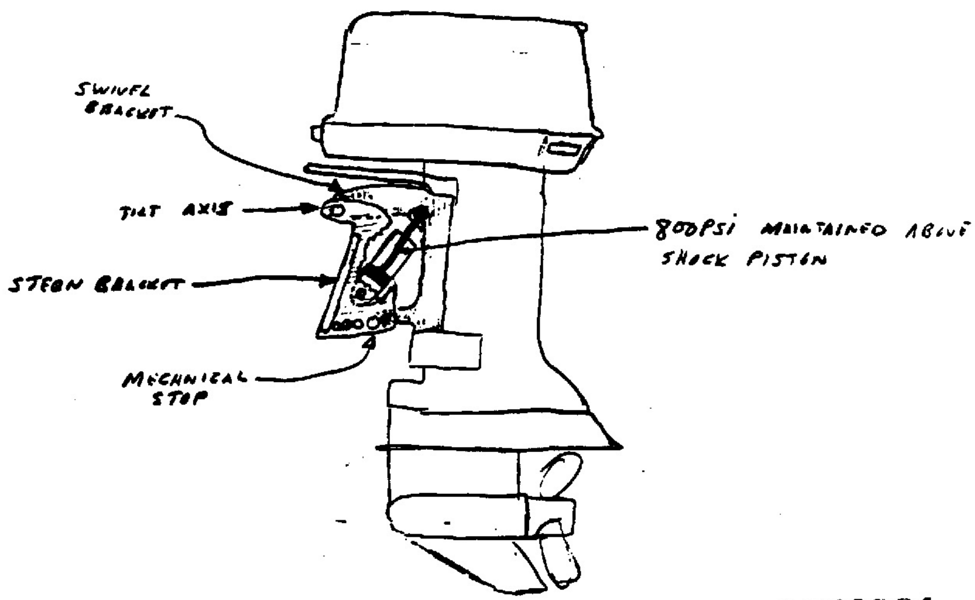

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Figure 17: Kueny Propeller Thrust Letter page 1

Mr. Mike Scott
October 16, 1990
Page 2

Please have Dr. Labra include this 250 pound force in his simulation.

If necessary, we could use an external pressure source rather than the outboard's own pump to supply pressure to the shock absorber. This would allow us to exactly duplicate prop thrust but would require the controlled external pressure source plus plumbing it to the outboard. It would also require some extra setup and monitoring on site, while the above force can be obtained quite easily.

To obtain this force requires that the adjustable thrust rod be set so that the motor is vertical and the trim motor (12 volt) be run "down" until the system bottoms. This is quite audible.

Sincerely,

D. F. Kueny
Chief Engineer - Advanced Outboards

DFK/rk101690

cc: E. Rose
R. Snyder

002080

Figure 18: Kueny Propeller Thrust Letter Page 2

Trim & Tilt Issues Created by Kuney's Plan

1. Normally boat operators trim their outboard motors in (close to vertical) to take off, then quickly start trimming them out (back and up) as the boat goes on plane. When a drive with a cage type propeller guard is is trimmed out at maybe 12 to 15 miles per hour, the leading edge of the drive slopes backward and downward. This allows people ran over by the boat to slide down the front side of guards instead of the guard squarely striking them.

   Leaving the outboard motor trimmed down during testing artificially inflates forces recorded by the crash dummy's head at the higher speeds used in these tests. See **Figure 16**.

2. Running the tilt cylinder pressure up to the relief valve setting before impact per Mr. Kueny's plan, takes away the cushion that would have been provided during impact as the pressure built up from a few PSI to the relief valve setting. This gradual pressure buildup would have lengthen the time of contact and reduced peak impact forces.

3. Page 18 of the 1989 NBSAC report said "even with an idealized cushioning material, not currently known to exist, head or body cavity strikes at speeds over 10 mph could likely be fatal." We recently wrote about the use of two-stage hydraulic cylinders to cushion propeller guard impacts.[30].

   Two-stage cylinders were previously developed and patented by several marine drive manufacturers and suppliers to protect the drive when it struck a log (log strike). The use of normal tilt cylinders during SUNY testing vs. two-stage cylinders which had already been patented by both Mercury and OMC increased impact forces. Use of two-stage hydraulic cylinders could also protect the propeller guard itself if it struck a log, rock, or stump.

Litigation Testing

Don Kueny and others in the industry have said the SUNY project was ran by technical people and scientists with some input from the lawyers that were involved. See **Figure19**.

In Elliott[31], Snyder said there was "some communication with or input from from the litigation people…" .

There was much more than that. While the scientist and technical people were operating the equipment, capturing and recording data, legal folks were calling the shots and paying the bills. See **Appendix C** for a summary of several OMC invoices related to SUNY testing.

The tilt cylinder issues identified above, lawyers paying the bills, use of a crash dummy with a neck spring many times stiffer than a human neck in compression, no comparison testing with an open propeller, no use of cadavers to verify the biofidelity of the crash dummy in these tests, extensive use of hedge words such as "may" in Scott's conclusions, inclusion of Mr. Snyder's editorial comments in the final paper, and still providing Event 1 propeller accident data vs All Event data are some of the indications the underwater head impact study was litigation testing.

---

[30] Reduce Peak Impact Force Boat Propeller Guards. PropellerSafety.com Gary Polson. October 30, 2022.

[31] Don Kueny deposition in Colby Elliott vs Bridgeport Boat Rentals, et al. Circuit Court of Jacks County, Missouri at Independence. No. 01CV215808. January 6, 2004.

DON KUENY
JANUARY 6, 2004

Multi·

Page 126

exists in any of these papers. I doubt that it does.

Q Did anything change as a result of these studies?

A Our knowledge base certainly increased. I don't know as any product changed. Our understanding of the physics of it improved.

Q So you had more detailed information about the mechanism of injuries to people that you intuitively knew occurred anyway, right?

A That's essentially correct, yes.

Q A whole bunch of scientists in the boating industry who were involved in litigation assembled to oversee that?

A I think that's a misnomer. I think a number of technical people and scientists probably with some communication with or input from the litigation people they were involved.

Q Were there lawyers up there for it?

A I don't recall that there were lawyers present, no. It was a technical exercise.

Q Certainly. How much total time did you devote to that up there?

A The physical testing I think went on for four or five days and I think I was present at least two and part of a third. I don't recall.

Figure 19: Don Kueny deposition in Elliot regarding SUNY

Scott's Conclusions
Time for one more Snyderism:

> *"Over 80% of the boating fatalities included in the U.S. Coast Guard's accident category, "Struck by Boat or a Propeller" occur at planing speeds, 25 mph or greater for most recreational boats."*

This statement often made by Mr. Snyder made it into Scott's conclusions along with a footnote, pointing back to the 1989 NBSAC report. This is the equivalent of money laundering. Mr. Snyder was able to get his Snyderism above into the 1989 report, giving it more credibility when it was later cited by Scott.

Note, the planing boats Snyderism above was not in the preliminary version of the paper, was not in the unnumbered proceedings version, was not in the page numbered Proceedings of the SAFE Symposium version, but came to life in the fourth version the paper that appeared in the SAFE Journal, 3 1/2 years after testing was completed.

> *"The results of this study indicate that impacts between a submerged head and a guard on a lower unit traveling at these speeds would most likely produce severe head and neck injuries. At these impact speeds it is difficult to prevent injury for individuals who are struck by a portion of the boat's lower unit, be it a propeller or a guard."*

This finding can be seen visually in **Figure 2** reproduced on the next page

As mentioned in the introduction, Scott's underwater head impact report says that if you are struck by the :

1. blue vertical edge of the propeller guard at speed you will suffer blunt trauma

2. yellow area, you can slide off the guard

3. orange area where the guard is stiffer, you may be knocked unconscious, increasing the probability you will drown

The most of the area in Figure 2 is yellow. It represents the region Scott said your head can slide off the guard. Without that guard your head would have passed through the propeller, much worse than sliding off the guard.

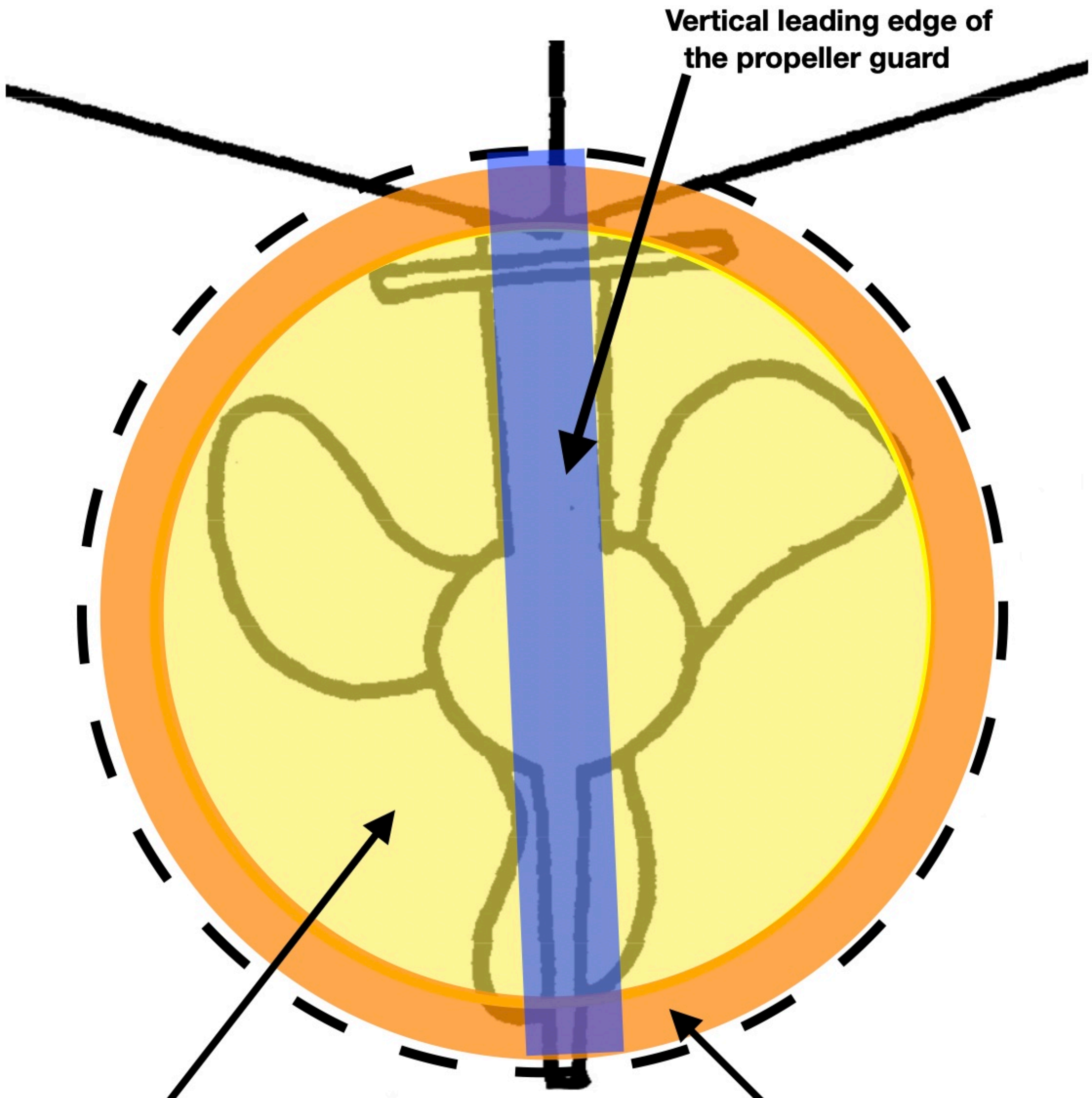

Figure 2: Propeller Guard Areas per 1989 NBSAC Study

A Real World Observation

I have been following propeller strikes for over 30 years. Over that time, thousands of propeller guards have been sold in the U.S., Australia, and the UK.

I only recall two propeller guard head strikes, both of which were outside the U.S.

1. April 29, 2004 - Mel Pengelly was racing in the Thundercat series (small high powered two man RIBs) off the coast of St. Peter Port in the English Channel. His boat struck a competitor's boat and rode up and over it. Pengelly recalls feeling the impact on his tiller (handle steering the outboard motor) when his propeller guard struck the other racer's head. That racer was taken to the hospital and told by doctors he could not race for at least five weeks. Pengelly and his co-racer were ejected high into the air after impact.

2. May 7, 2011 - Matt, 27, dove from the deck top of a houseboat at Broken Bay, North of Sydney Australia. Matt hit his head on the engine cover and fiberglass propeller guard. He suffered deep head and facial wounds, a broken jaw, broken ribs, a punctured lung, concussion, and lost some teeth.

Two propeller guard head strike accidents, both outside the United States in over 30 years. Both men likely received some blunt trauma injuries, but both accidents leave us thinking they are likely better off than they would have been if no propeller guard was present.

Meanwhile we are approaching 10,000 BARD reported boat propeller accidents since Scott's propeller guard head impact study was conducted at SUNY.

Injury Indexes

Appendix A

Head Injury Criterion (HIC)

The study of head injuries, like several other fields of injury, has developed an index based on parameters the head is exposed to in order to estimate possibility and extent of injury.

The Biodynamic Research Corporation (BRC) head impact report used the Head Injury Criterion (HIC) which is also used by the National Highway Transportation Safety Association (NHTSA).

The index is a measure of “the potential for a closed head injury due to the translational acceleration of the skull.”

Basically, acceleration of a human head can create internal injuries that cannot be seen on the outside of the persons head.

The equation based on head acceleration and the time over which it occurred is somewhat complex. See page IV-6 of their preliminary report.

$$HIC = \left\{ (t_2 - t_1) \left[\frac{1}{t_2 - t_1} \int_{t_1}^{t_2} a(t)\, dt \right]^{2.5} \right\} \max$$

> *“where a(t) is the resultant acceleration of the skull, and t_1 and t_2 are the beginning and ending times of the integrated acceleration pulse. The time interval t_1 to t_2 is selected to maximize the HIC value.”*

An HIC of 1,000 was used by the propeller guard head impact paper, and others, as low limit to when one could anticipate closed head injuries.

An HIC of 1,000 corresponds to an 18 percent probability of a severe head injury, 55 percent probability of a serious injury, and a 90 percent probability of a moderate head injury to the average adult.

Based on this criteria, only the 15.7 mph center impact would have produced a closed head injury with its HIC score of 1300. Note this score was measured on a Hybrid III crash dummy with a very stiff neck in compression (increases the score).

The authors attribute the low HIC scores to the shape of the acceleration curve (short duration, high peak, followed by a succession of peaks of smaller amplitude). They say this is common of sharp impactors on cadaver skulls. The leading edge of this particular propeller guard is not a broad flat surface.

The HIC discussion and data have been compressed into a single paragraph on page 21 of the SAFE Journal version of the paper.

In terms of airbags, NHTSA has since changed the maximum time over which these calculations are made and the resulting score criteria.

Added Mass

Appendix B

Added Mass

As described in the Safe Journal version of the head impact paper on page 15:

> *"The apparent inertial mass of a body accelerated in water is significantly increased because the water around it must also be accelerated.This apparent increase mass is called added mass"*

The amount of added mass depends on density, depth, and if it is being pushed horizontally or vertically.

1/2 of the object's mass is often used to represent added mass for objects floating near the surface.

Similar values are used for humans or human body parts because our bodies are close to the density of water.

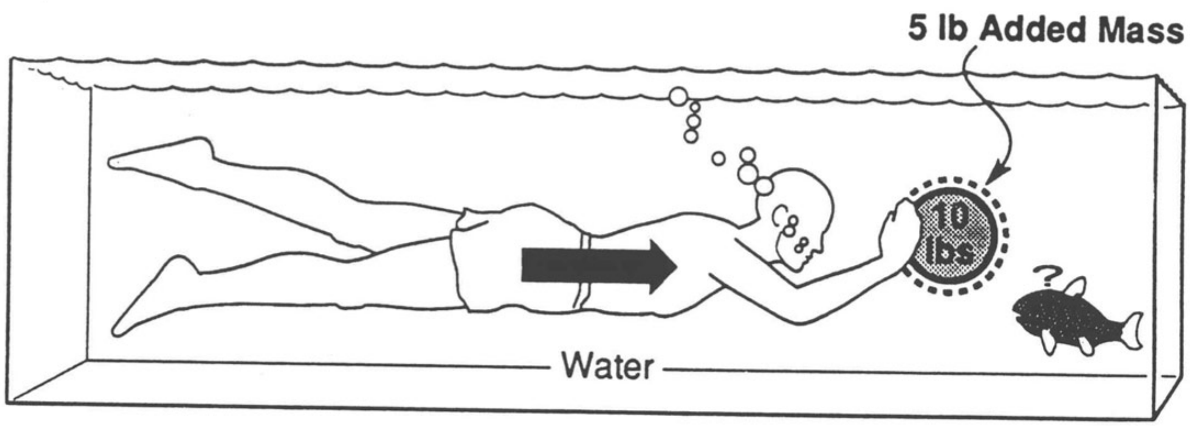

Figure 3. The 10 lb Sphere Feels Like a 15 lb Sphere When the Swimmer Starts to Push It Because of the Added Mass.

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Figure 20: Added Mass

As to the image above, if the 10 pound sphere was a small diameter, steel shot put, the added mass would be much less than five pounds and determined by analysis of the size and shape of the object.

While this may be "picky", if the authors did not catch this issue, they may not have caught others.

SUNY Invoices

Appendix C

SUNY Invoice Notes

This section of our analysis of Scott's head paper (our **Volume 3**) will also be utilized by our analysis of Kress' leg impact paper (our **Volume 4**).

Several OMC SUNY related invoices are summarized on the following pages. These invoices are a small portion of OMC's legal bills sent to their insurance trust in this era.

As mentioned earlier, two legal firms were heavily involved in OMC's propeller accident legal defense in the early 1990s, Snell & Wilmer, and Bowman and Brooke.

These bills indicate a sense of urgency as propeller guard lawsuits are piling up. OMC is trying to streamline legal operations by gathering all this information and bundling it digitally for regional attorneys.

These bills show OMC and Mercury's in house attorneys were involved in the SUNY testing project, and the law firms handling their propeller cases were heavily involved. Engineers, technicians, and researchers were conducting the tests at SUNY, but the project was under the control of lawyers.

OMC's Law Department used Cindy Moore of Crawford & Company (a large insurance / claims management place) to pay the bills sometimes from OMC's trust funds.

Names associated with SUNY testing that show in the bills

Snell & Wilmer - legal firm used by both Mercury and OMC

Bowman and Brooke - legal firm used by both Mercury and OMC

Biodynamic Research Corporation (BRC) - where Mike Scott and his crew were employed

University of Tennessee - where Tyler Kress was studying for his Phd

University of Louisville - where David Port was studying for his Phd

Authors of Head Impact Study	**Authors of Leg Impact Study**
Michael Scott of BRC	Tyler Kress
John Labra	John Snider
Herbert Guzman	Jack Wasserman
James Benedict of BRC	Guy Tucker
Harry Smith	Dr. Peter Fuller
James Ziegler	David Porta

Others involved in the SUNY project included:

Name	Position
Alex Marconi	OMC corporate lawyer, later worked for Snell & Wilmer
Joe Pomeroy	Mercury Marine corporate lawyer
Don Kueny	OMC Chief Engineer, and latter President, now an expert witness
Richard “Dick” Snyder	Mercury Marine in house propeller accident expert
Ellen Waxman	Snell & Wilmer attorney
Albert “Bert” D. Dham	coordinating SUNY project at Snell & Wilmer
James H. Raddin	handled some of the airfare for the project at BRC
Dr. Albert H. Burnstein	bone strength specialist from Case Western Reserve University participating in the testing.
Ellen J. Waxman	attorney at Smith & Wilmer heavily involved in the SUNY project

No.	Date	Invoice Description
1	16 Feb 1991	OMC Bill from Bowman and Brooke PDF Page 4. 3 December through 14 December, 1991 - numerous listings for correspondence with Kress and Scott, underwater testing, telephone conferences with Benedict, Dr. Fuller, Dr. Burstein.
2	7 Mar 1991	OMC Bill from Snell & Wilmer PDF Page 3 12/05/90 Conference with Marconi on underwater testing PDF Page 4 12/10/90 Conference with Marconi and Radden on SUNY Testing, With Palmer on a mathematical model. 12/12-13/90 Attend SUNY testing of head and limb impacts.
3	16 Apr 1991	OMC fax of 7 February 1991 Biodynamic Research Corp bill Major players at SUNY are billing for Case Review and Analysis, including Scott's bill for about $30,000. Also airfare bills, hotels, and travel expenses for several involved with the SUNY project.
4	27 April 1991	OMC 1st bill from Snell & Wilmer of this same date for $17,700.32 PDF Page 4. 1/24/91 Marconi (OMC in house lawyer) and Pomeroy (Mercury Marine in house lawyer) and working together to handle Discovery items related to prop guard tests. They are reviewing their Interrogatory answers together. Above on the same page, 1/23/91 Marconi is working on Disclosing the SUNY testing. Below on same page, 1/31/91 Scott and Snyder are talking about the completion of the SUNY test results.

No.	Date	Invoice Description
5	27 Apr 1991	OMC 2nd bill from Snell & Wilmer on this same date for $12,376.76 PDF Page 3 2/01/91 - 2/21/91 multiple conferences regarding SUNY, the SUNY Conference, Scott, Snyder, Snider, Dahm -coordinating SUNY research, Kull, Marconi, Fuller PDF Page 4 2/25/91 - 2/28/91 develop agendas, conferences, SUNY meeting arrangements. Marconi, Scott, Dahm, Snider, Goulder, Fuller, and Snyder 2/01/91 Finalized Getz testimony summary
6	17 May 1991	OMC bill from Bowman & Brooke for $4,523.53 PDF Page 4. 3/05-07/91 updating SUNY testing file, conference with Robert Taylor on forwarding accident reports to the Coast Guard, preparing for SUNY testing meeting in Chicago, attending SUNY testing meeting. PDF Page 5. Obtaining certified copies of the documents reviewed by the NBSAC propeller guard subcommittee.
7	3 June 1991	OMC bill from BRC for $35,469.00 for use of the physical facility at SUNY. Note OMC paid half of the $70,000 plus bill. (meaning Mercury paid the other half).

No.	Date	Invoice Description
8	3 June 1991	OMC bill from Snell & WIlmer for $10,959.13. PDF Page 3. 3/01/91 - 3-25/91 Preparations for the SUNY test meeting in Chicago PDF page 4. 3/07/91 Chicago meeting regarding SUNY testing with experts and counsel. PDF page 5-6. 3/13/91 Phone conference regarding materials required for Mercury trial. PDF page 6. 3/14/91 Conference with Mike Scott regarding expert interrogatories answers. PDF Page 8 3/22-25/91 Phone conference with Kress & Waxman regarding meeting on SUNY results. PDF Page 9 Several costs associated with the Chicago meeting on SUNY results.

No.	Date	Invoice Description
9	9 July 1991	OMC bill from Snell & Wilmer PDF Page 3. 4/10-19/91 reviewing BRC report, review materials regarding testing in Mercury's possession PDF Page 4 4/20-29/91 Telephone conference with Snyder, telephone conference with Marconi, meeting with John Snider in Knoxville Tennessee regarding SUNY materials, revision of SUNY test interrogatories, phone conference with Mike Scott on report status. PDF Page 5. 4/3-4/91 Assemble and organize Mercury test reports. 4/8/91 conference with Pomeroy regarding SUNY meeting. PDF Page 6- Page7 4/9-10/91 obtaining certified copies of USCG NBSAC report materials. 4/12/91 phone conference with Don Kueny on his SUNY meeting attendance. PDF Page 8 4/17/91 locating, reviewing, and copying SUNY documents for legal purposes. PDF Page 9 Deliver SUNY test documents to Waxman. PDF Page 10 4/29/91 Phone conference with Snyder, updating legal database with SUNY documents supplied by Mercury.
10	3 August 1991	OMC bill from Bowman and Brooke for $4,896.01. PDF Pages 4-5. 5/6-29/91 Numerous references to SUNY project and its cost. Also to FAA (Failure Analysis Associates - Robert Taylor).

No.	Date	Invoice Description
11	3 August 1991	OMC bill from Snell & Wilmer for $14,324.40. PDF Page 3. 5/03/91 reviewed Kress SUNY data and copyrighted the photographs 5/7/1991 - 5/9/1991 setting up Kress, Scott, and other SUNY researchers for depositions. PDF Page 4. 5/14/1991 talking with Kress and Porta regarding depositions 5/14/1991 Reviewed BRC draft report in preparation for meeting at BRC. PDF page 7. 5/14/1991 Drafting interrogatory responses from Kress and Scott. 5/14/1991 Review various SUNY documents for inclusion in database. (they are preparing to use these materials in legal cases before the study is published.)
12	20 August 1991	OMC bill from Bowman and Brook for $2,664.15. PDF page 4. 6/21/91 Telephone conference with BRC billing regarding dates of invoices and Mercury Marine payments.
13	20 August 1991	OMC bill from Snell & WIlmer for $9,451.83. PDF Page 7. 6/12/91 revise list of videos in OMC data base; add SUNY videos to same. 6/12/91 conference with Scott on production of SUNY data; Assemble and organize same and prepare for Production (produce in legal discovery).
14	20 August 1991	OMC bill from Fuller at University of Louisville regarding legs for SUNY testing via Snell & Wilmer for $300. PDF Page 3 Snell & Wilmer bill refers to the expense as being “rendered in this litigation”, does not sound like it is an academic research project

No.	Date	Invoice Description
15	12 October 1991	OMC bill from Snell & Wilmer PDF Page 3. 7/15/91 Phone conferences with Snieder, Kress, & Fuller on report status. 7/16/91 Phone conference with Fuller on report status, prepare letter to Pomeroy. 7/18/91 Phone conferences with Scott and Press regarding SUNY reports. 7/30/91 Phone conferences with Scott and Press regarding the report. PDF Page 5 7/26/91 **Assemble cvs of expert**s Benedict, Blount, Getz, Labra, Kueny, and Snyder.
16	21 Nov 1991	OMC bill from Snell & Wilmer for $3,965.44. PDF Page 3. 8/27/91 - 9/19/91conferences regarding the reports with Kress, Scott, and Kueny. Review of the Tennessee report (Kress). 9/25/91 Conference on the Tennessee report **regarding revisions**.
17	7 January 1992	OMC bill from Snell & Wilmer for $2,059.28. PDF Page 3. 10/10/91 review of SUNY and BRC reports. Phone conference with Marconi and others regarding the reports and suggestions for modifications. **They are suggesting edits to the reports.**
18	7 January 1992	OMC bill for **$36,229.50** from University of Tennessee for the Kress leg study. Note- Page 2 two shows the bill was for twice that amount and OMC only paid 1/2 (meaning Mercury paid the other half). The letter from Bowman and Brooke on page three verifies Mercury was to pay the other half.

No.	Date	Invoice Description
1918	21March 1992	OMC bill from Snell & Wilmer for $1,829.32 PDF Page 3. Waxman 1/24/1992 phone conference with Marconi (OMC lawyer), Pomeroy (Mercury lawyer), Dick Snyder (Mercury), Mike Scott of BRC, and Warren Platt a Snell & Wilmer attorney regarding the TENN (Kress) and BRC (Scott) reports; Mercury production of SUNY test documents and meeting regarding same. Preparing a memo on status of the BRC report. 1/27/91 Conference with Dick Snyder regarding status of the Tennessee BRC reports, phone conference with Scott and Kress regarding status of the reports. Read BRC revised report, prepared letter to Marconi (OMC lawyer) regarding it. 1/30/1992 read **BRC revised report.**
20	10 Feb 1993	OMC bill from BRC for $14,129.82. This is the final bill from BRC. PDF Page 2 Shows Mercury has been paying half the bills. This invoice includes a list of all the previous BRC bills which total about $162,000 which were evenly split between OMC and Mercury. PDF Page 3. a Biodynamic Research Corporation letter about the invoices says Dr. Scott will be sending a copy of the **final report previously issue to Alex Marconi (OMC lawyer) in October 1992**. PDF Pages 4-16 are copies of previous billing statements. They show Dr. Scott receiving about $55,880 for his work during this time period including being paid for travel time on at least one occasion.

Appendix D

Mercury Marine, OMC, Kress, & Scott Public Comment letters

Background Information on USCG Public Comment Documents

United States Coast Guard has proposed various boat propeller safety regulations. They often begin with an announcement in the Federal Register requesting public comments in specific areas of propeller safety as the Coast Guard begins to create or refine a proposal.

A timeline of these proposed regulations is available in our post "USCG Propeller Safety Regulations Timeline / History".[32]

A 1995 request for public comment on a proposal named, "Propeller Accidents Involving Houseboats and Other Displacement Type Recreational Vessels" originally known as CGD-95-041 eventually became rolled into USCG-2001-10299 and was withdrawn on December 10, 2001.

The project morphed through time, multiple comment periods, and several public hearings.

Mercury Marine, Outboard Marine Corporation, and Tyler Kress submitted public comments against the proposal.

Richard Snyder, Tyler Kress, and Robert Taylor attended one or more public comment meetings.

The boating industry pointed to the 1989 NBSAC study, the head impact study, and the leg impact study as reasons for rejecting the proposal.

Documentation includes:

1. Richard Snyder public comment letter   July 6, 1995   USCG-2001-10299-46

2. OMC public comment letter July 7, 1995 USCG-2001-10299-47

3. Head impact study as faxed from Bowman and Brooke (law firm handing some of OMC's propeller cases). This document was attached to OMC's public comment.

4. Tyler Kress public comment letter August 29, 1996. USCG-2001-2020

5. A version of the leg impact study was attached to Kress' public comment letter.

6. OMC public comment letter. 29 August 1996. Basically states they still have the same opinion as in their earlier letter. USCG-2001-10299-2021.

7. OMC public comment letter. July 7, 1995. Was attached to OMC's letter above.

   Note: 1,2, and 3 appear to have been filed at the same time. Over a year later 4,5,6, and 7 were filed at the same time.

8. The full 55 page 1989 NBSAC report is also in the 2001-10299 docket under three identifications: CG-95-041, USCG-10299-146, USCG02001-10299-25. Dated August 24, 1995. We are not physically attaching a copy here as it is available online at:
https://www.propellersafety.com/wordpress/wp-content/uploads/1989-nbsac-propeller-guard-study.pdf

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[32] USCG Propeller Safety Regulations Timeline / History. Gary Polson. PropellerSafety.com. January 22, 2013.   https://www.propellersafety.com/6719/regulations/propeller-guard-regulations-timeline/

Appendix E

Neck Injury Criteria Updates

Injury Assessment Reference Values (IARV)

Most if not all parts of our bodies can be physically injured, such as by dropping something on them, by our bodies impacting or being impacted by something, by acceleration, deceleration, temperature, sound level, pressure, etc. Over time several fields of study have tried to define the bounds of forces, times, etc. at which:

1. individuals of a specific population will begin to be injured.
2. about half the population will be injured.
3. about 95 percent of the people will be injured.
4. or at least define safe and unsafe boundaries.

These values are sometimes referred to as Injury Assessment Reference Values, or IARV.

Not many people want to volunteer for a study in which they could be critically injured or killed. Therefore most studies of this nature are conducted with cadavers, sometimes called Post Mortem Human Subjects or PMHS, or with anthropometric dummies sometimes called crash dummies.

Many studies over the last few decades, including Scott's study, have been performed with the Hybrid III 50 percentile adult male ADT (Anthropomorphic Test Device).

As researchers began trying to determine bounds for certain types of injuries, they found the Hybrid III dummy and even cadavers or parts of cadavers do not always replicate humans. Conversions have been developed to allow"scaling" from the Hybrid III or cadavers to living humans.

Mertz and Neck Compression

As mentioned earlier in the **Scott's Propeller Guard Head Impact paper Reference #10 / Mertz** section of this report, H.J. Mertz was among the first to develop bounds for human necks under axial compression. Mertz along with three other researchers tried to recreate high school football player neck injuries from striking a tackling block (spring loaded, padded, tackle dummy). Mertz impacted a helmeted Hybrid III dummy with a spring loaded tackle dummy at various speeds to determine conditions under which some accidents occurred.

With limited data on the injured players and the impacts that injured them, Mertz cautioned:

"Because of the limited information relating neck loadings measured with the GM Hybrid III dummy to known human neck injuries, these injury references should be used only as guides in interpreting data obtained with the dummy. Neck injuries that might result from bending, shearing, axial tension, or combinations of these loadings are not applicable to either of these axial compressive force references."

Chart 1 resulting from Mertz's work, produced earlier is reproduced on the next page.

From the literature, H.J. Mertz was perceived as doing excellent research. However his correlation with human necks was sketchy due to the limited number of events and minimal data available. Nonetheless, Mertz's work and especially his Proposed Neck Injury References for axial compressive neck force curve were cited in the literature for several years. Even though Mertz's data was limited to the outcome of the event and a few bits of data about the person and the event, his work was the only research available validating Hybrid III dummy neck axial compression impacts with human data.

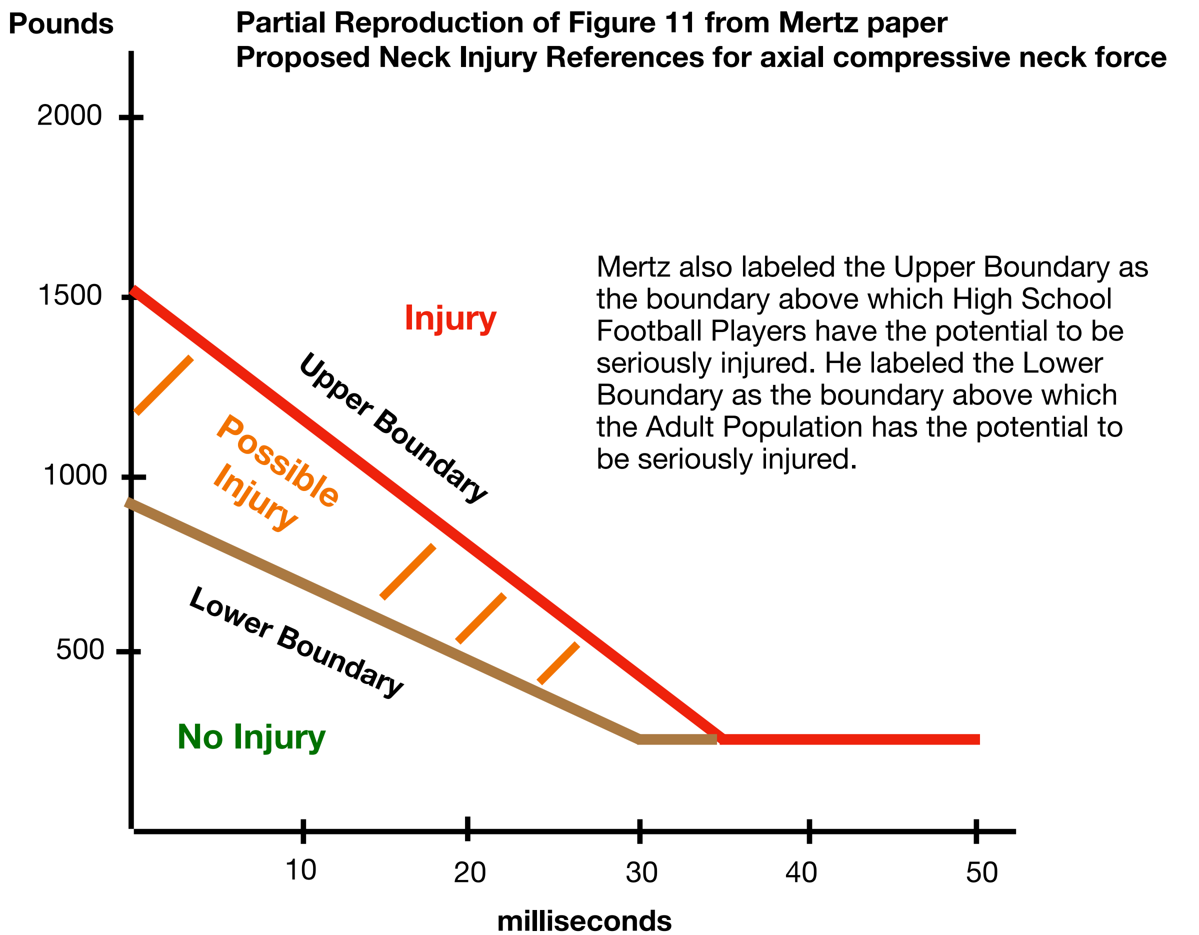

Chart 1: Mertz Axial Compressive Neck Force Boundaries

Now, decades later, Mertz's work is still heavily cited, but additional research is now available (see Annotated Bibliography on next page).

Research in the field of axial neck compression is especially challenging in part because:

1. The neck is near the back of the skull (offset) and at an angle to the skull.
2. The top of the human head does not always vertically impact a flat surface.
3. Impact at any other angle makes things much more complex.
4. The head often slides some direction after impact, lengthening time of contact, lowering peak forces, and bringing additional complexity to the calculations.
5. Results need to be compared to cadavers or humans.

If you recall, in Scott's underwater head impact paper there was an issue with the Hybrid III dummy's head skin sticking to surfaces vs. sliding.

An **Annotated Bibliography** of more recent works is provided on the next page.

Axial Neck Compression Annotated Bibliography

1. Collision With Spring-Loaded Football Tackling and Blocking Dummies: Report of Near-Fatal and Fatal Injuries. Torg, Quedenfeld, Thieler, Lignelli. Journal of the American Medical Association. (JAMA). September 13, 1976. Vol.236. No.11.
   This paper contains some of the accidents lated cited by Mertz.

2. An Assessment of Compressive Neck Loads Under Injury Producing Conditions. Mertz, Hodgson, Thomas, Nyquist. The Physician and Sportsmedicine. November 1978.
   Mertz's football impact paper.

3. Injury Risk Assessments Based on Dummy Responses. Harold J. Mertz. Accidental Injury. Chapter 5. Pgs. 89-102. 2002.

4. Cervical Spine Tolerance and Response in Compressive Loading Modes Including Combined Compression and Lateral Bending. Daniel Toomey. Dissertation. Wayne State University. 2013.
   Toomey's dissertation.

5. The Hybrid III Upper and Lower Neck Response in Compressive Loading Scenarios With Known Human Injury Outcomes. Toomey, Yang, Ee. Traffic Injury Prevention. Published Online 11 October 2014.
   Paper based on Toomey's dissertation.

6. Biomechanical and Scaling Bases for Frontal and Side Impact Injury Assessment Reference Values. Mertz, Irwin, Prasad. Stapp Car Crash Journal. Vol.47. October 2003. Pgs.155-188.
   A single document listing IARV's for the Hybrid III dummy.
   This paper is also available as SAE paper 2016-22-0018. The SAE version corrects errors in the original paper and updates regulatory compliance limits.

7. Toward a More Robust Lower Neck Compressive Injury Tolerance - An Approach Combining Multiple Test Methodologies. Toomey, Yang, Yoganadan, Pintar, Ee. Biomedical Engineering. Biomedical Engineering Faculty Research Publications. Wayne State University. 2013.

8. A Neck Compression Injury Criterion Incorporating Lateral Eccentricity. Whyte, Melnyk, Toen, Yamamoto, Street, Oxland, Cripton. Nature. Scientific Reports. Published 28 April 2020.

Dr. Daniel Toomey is among the most prolific writers in this field since the Mertz paper. One of Toomey's co-authors has been Dr. Chris Van Ee.

The boating industry could easily ask Mr. Toomey to take a fresh look at Scott's data. Mr. Toomey and Mr. Ee are both employees of Design Research Engineering (DRE), a firm the boating industry often hires in propeller guard law suits.

Appendix F

Eiband Tolerance Curve

Eiband Tolerance Curve was an early Injury Assessment Reference Value (IARV)

In June 1959, NASA published a summary of the literature on Human Tolerance to Rapidly Applied Accelerations. Martin Eiband authored the survey.

NASA was becoming concerned about the accelerations of human occupants in space vehicles as they accelerate from the earth, decelerate on return or in preparation for landing upon another body, and land.

Eiband found several spineward (up your spine) acceleration studies. Eiband charted the data. He defined boundaries of the various injury levels on a log log chart with uniform acceleration on the vertical axis and time duration on the horizontal axis.

Over time, these curves became known as Eiband Tolerance Curves after Martin Eiband,

Military aeronautics later used them as a means to design aircraft ejection seats.

The curves were later used in aviation to study crash survivability.

Now, decades later, Boating industry expert witness used them in at least two recent boat propeller injury cases.

The Garcia Case

An undocumented female floating on an inflatable ring was crossing the channel at night near Brownsville, Texas to get to the United States. She was ran over by a Coast Guard patrol vessel, struck by its propellers, and died.

The vessel was powered by three large Mercury outboards.

A team of three experts: Dr. Thomas W. Edgar, Dr. Jonathan Slocum, and Dr. Alexander Slocum were among those representing the industry in Garcia.

Their September 2018 report put forth the scenario the lady was struck by the keel of the approximately 7,000 pound vessel, then struck by the skeg and propeller of the middle outboard of the triple 300 horsepower Mercury Verado outboards powering the vessel.

They estimated the lady's body was accelerated about 53 g's when it was struck by the keel. An Eiband curve was used to show her injury from striking the keel "would likely be catastrophic in nature and therefore non-survivable."

We point out the Eiband curve was developed for applications like ejections seats where the person is very tightly bound to the seat by multiple straps and harnesses. The curve from the experts' report (**Chart 3**) even says the limits on the curve are for ejection seats. The curve is for vertical accelerations of a seated, securely strapped in body, with special attention to the spine. It is not for a single body part being impacted by something.

Experts went on to attribute the cause of a deep laceration to being struck by the outboard motor skeg, prior to being struck by the propeller.

They rated both impacts as being non-survivable, a non-survivable impact with the keel followed by a non-survivable impact with the skeg.

The experts said a propeller guard would have just added one more non-survivable impact to the event.

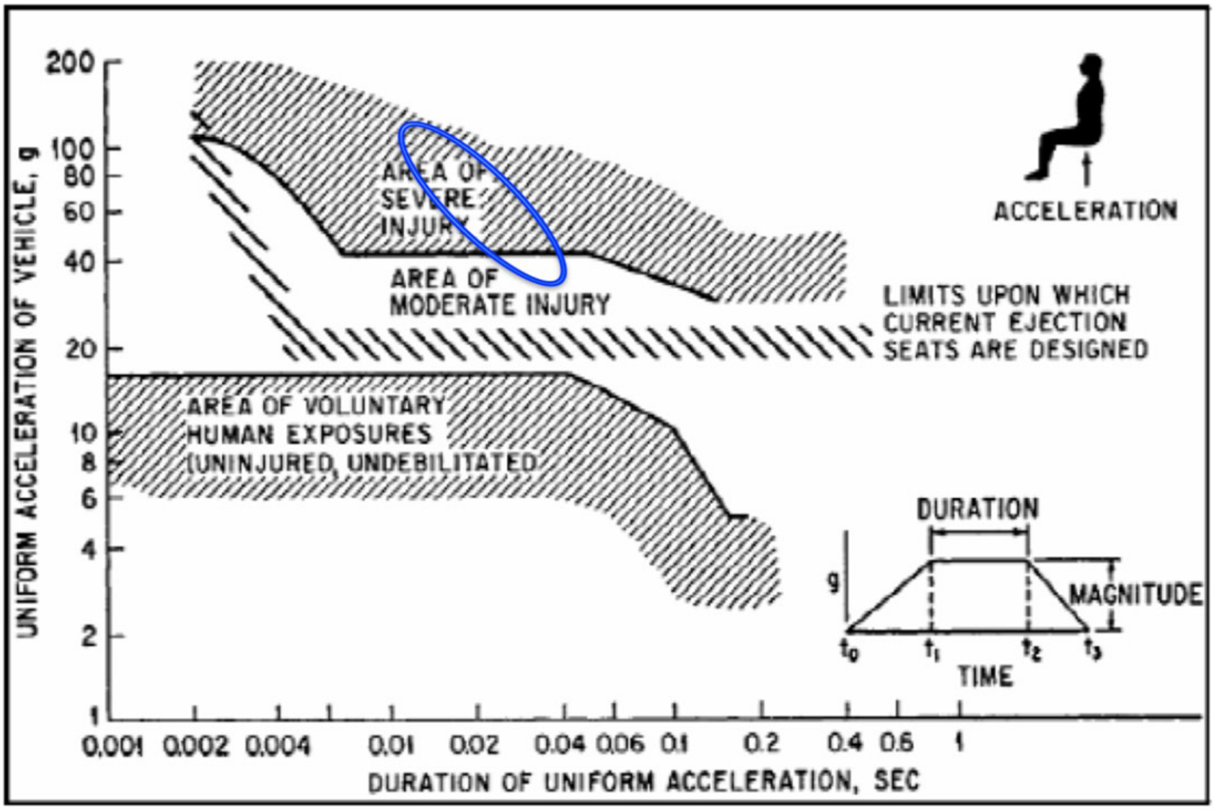

Figure 7 - Eiband curve with Accelerations and durations of this event superimposed by the blue ellipse.

Chart 3: Eiband Tolerance Curve: Keel Impact in Garcia Case

Reed vs. Tracker Marine

Chart 4 on the next page comes from Dr. Alexander Slocum, Jr.'s report in Reed vs. Tracker.

While Dr. Slocum Jr. has far more medical experience than I do, I have a hard time with the sentence in red in our **Chart 4** on the next page from his April 2021 expert report:

> *"It is reasonable to assume that any amount of force that would cause non survivable injury when applied to the body of a victim, would also result in a non-survivable pattern of injury when applied to the victim's head."*

Chart 4 from Slocoum Jr.'s report is the same ejection seat design chart they used in the Garcia case.

Human heads behave differently in impacts resulting in accelerations in at least 5 directions (up, down, left and right, toward the front, and toward the rear. The head can take various forces and accelerations depending upon their direction, location, and the size, stiffness, and shape of the impactor.

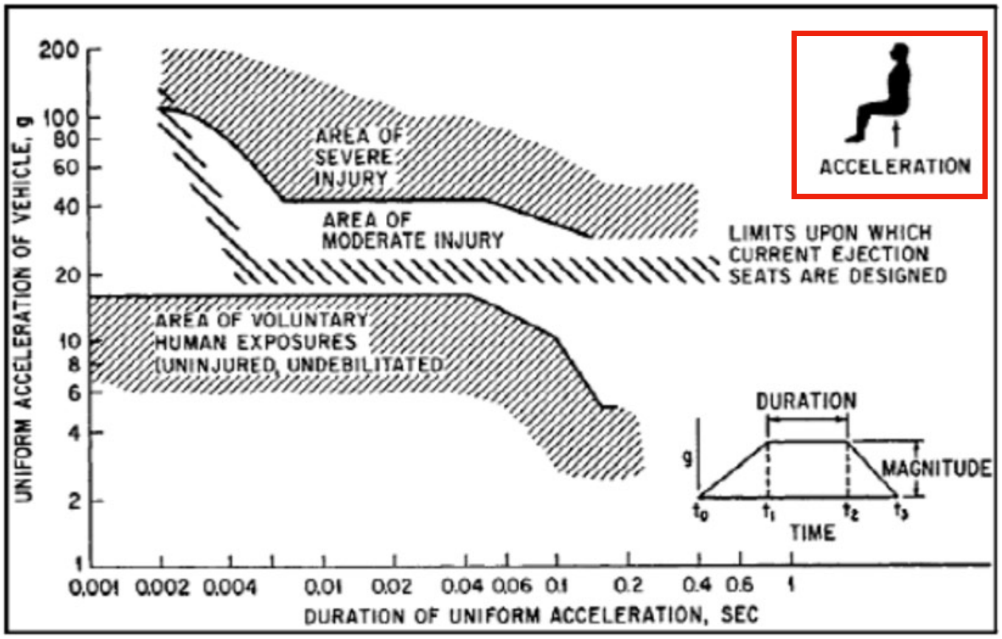

Figure 2: Eiband tolerance curve, illustrating that the severity of injury caused by an acceleration increases with the duration of time to which an individual is subjected to that acceleration.

The primary difference lies in the fact that, based on the autopsy images the largest energy transfer most likely occurred through the victim's skull, and the Eiband Tolerance curves primarily are used to describe situations where an individual is sitting in a chair or seat (not resting on their head). It is reasonable to assume that any amount of force that would cause non-survivable injury when applied to the body of a victim, would also result in a non-survivable pattern of injury when applied to the victim's head. To analyze the circumstances surrounding the interaction between the boat and the victim's head, I utilize equations describing collision physics, based on Newton's laws of motion, to describe the magnitude of the energy transfer between the boat and the victim.

Chart 4: Eiband vertical acceleration

We will leave it to other medical and biomechanics types to further address the issue above. Just like the Hybrid III dummy was built to record data in forward crashes, not to be struck in the head, Eiband Tolerance Curves represent a body very securely harnessed and belted into a strong, supporting seat that is vertically accelerated, the person is not being struck in the head.

We see Dr. Slocum Jr.'s collision analysis calculated the total weight of the boat, those on board, plus the gear onboard and used this total mass in his calculations to determine the g's and force applied to accelerate the girl's skull. Scott only used the weight of the outboard motor in his calculations.

Scott did not have a boat attached to the outboard motor. The rotating arm maintained speed of the outboard motor. The arm did not slow down during impact. Scott's setup forced the dummy's head back and down and/or to the side. The outboard motor was allowed to swing up against its log strike system if it struck a major object (like a human head at speed).

Scott's team placed an accelerometer in the rear of the torpedo to measure acceleration of the motor about its tilt axis. (Page II-3). Page III-8 notes "No meaningful data was obtained from the transducer mounted on the torpedo of the lower unit, apparently because of vibrations. Consequently, this data is not discussed in the report."

In Reed, the girl had a 3 centimeter skull fracture. Slocum chose three boat speeds (5,7,10 mph), He used the time for the vessel to cover the 3 centimeter skull fracture to determine the duration of impact. Slocum then used the boat speed as the final speed of the victim, calculated acceleration from rest to that speed within time to cover 3 centimeters, then used mass of the head to calculate the force.

As in the Garcia case, the expert postulated the victim was fatally struck by the boat, not by the propeller. He suggests she contacted a pontoon the fuel tank, or the skeg. He points out his analysis would also hold true if the young woman's head had struck a propeller guard.

Slocum went on to compare his impact force results with Scott in **Chart 5** below.

Table 2: Total force on victim's head, compared with experimental results reported by Scott *et al* (Table 3, page 19).

Speed (mph)	Total Force (lb-f)	Scott *et al.* (lb-f)
10	2560	4043
7	1239	2572
5	640	643

Chart 5: Slocum Compares His Results With Scott

Slocum said:

> *"The results of my analysis correlate well with a study by Scott et al from 1994, where the authors reacted a similar model and conducted an experimental analysis using a cage-type propeller guard and an instrumented mannequin. While my analysis underestimates the measured force required by Scott et al, this only shows that a higher boat velocities the impact would cause even more severe injury."*

Slocum failed to recognize Scott's larger forces are in part due to the spring in the Hybrid III dummy's neck being much stronger than in humans. The numbers were further compounded by Slocum including the mass of the boat while Scott did not.

We suggest the Head Injury Criterion (HIC) presented in **Appendix A** is a more appropriate injury measure in propeller guard head strikes than Eiband Tolerance Curves.

The final versions of Scott's paper (the one printed in the SAFE journal) mentions the Head Injury Criterion near the end of the paper and says only the two 15.7 mph centered impacts (Tests 9 and #10) would produce closed head injuries with an HIC value of greater than 1,000. Please note these measurements were reached with the stiff neck spring.

Appendix G

Circular Verification of the Mathematical Model

The Computer Model

One purpose of impact testing was to assess the validity of a mathematical model that predict blunt trauma impact forces in underwater impacts with lower units of marine drives.

The model is cited as:

Labra, J.J.; Benedict, J.V.; Ziegler, J.; *The Human Biodynamic Response to Underwater Impacts.* The paper is listed as being in preparation in September 1992.

The authors listed above are Biodynamic Research Corporation (BRC) employees, the same group Kress was hired from. Some if not all of these individuals were involved in the actual impact testing.

Page 17 of the SAFE Journal version of Scott's paper identifies the parameters used in the simulations in **Figure 21** on the next page.

Hybrid III dummy data was used in the model, including Hybrid III neck axial stiffness, known to be multiple times the axial stiffness of human necks.

Table II.
PARAMETERS USED IN SIMULATIONS

OUTBOARD IMPACT DATA

Total Weight: 265 lbs.
Mass Moment of Inertia: 149 lb-in-s^2
CG to Motor Mount Location: 2.81 in.
Prop Centerline to CG Location: 26.80 in.

HYBRID III DATA*

Chin/Neck Interface Rotational Stiffness: 1266 in-lb/rad
Suprasternale Rotational Stiffness: 811 in-lb/rad
Chin/Neck Interface Rotational Damping: 13.2 in-lb-sec/rad
Suprasternale Rotational Damping: 0 in-lb-sec/rad
Neck Axial Stiffness: 3000 lb/in
Neck Axial Damping: 8.6 lb-sec/in

Head Weight: 11 lbs
Neck Weight: 3.8 lbs
Thorax Weight: 68 lbs

Head Mass Moment of Inertia: 0.28 lb-in-sec^2
Neck Mass Moment of Inertia: 0.06 lb-in-sec^2
Trunk Mass Moment of Inertia: 18.9 lb-in-sec^2

Head Radius: 4.1 ins
Neck Radius: 2.5 ins
Thorax Radius: 6.4 ins
Neck Atlas to Head CG Distance: 2.1 ins
Neck Length: 4.5 ins
Trunk Length: 20.4 ins

* **Where data from Hybrid III ATD were not available, data were based on cadaver data.**

Figure 21: Computer Model Parameters

Table III. Peak Values in the Centered Impacts and Simulations

TEST # IMPACT SPEED	IMPACT TESTS			SIMULATED IMPACTS		
	IMPACT FORCE (lb)	HEAD CG ACC. (g's)	NECK AXIAL LOAD (lb)	IMPACT FORCE (lb)	HEAD CG ACC. (g's)	NECK AXIAL LOAD (lb)
1 (2.5 mph)	187	7	125	175	10	90
2 (5.1 mph)	347	15	219	667	39	206
3 (5.1 mph)	643	37	284			
4 (5.1 mph)	662	38	251			
5 (7.7 mph)	2572	150	461	2202	127	420
6 (7.7 mph)	2431	142	433			
7 (10.4 mph)	4043	233	625	4111	237	611
8 (10.4 mph)	4579	260	605			
10 (15.7 mph)	5812	331	824	6154	353	822

Figure 22: Comparing Test Data to Mathematical Model

Figure 22 above compares Scott's center strike test data with the mathematical / computer model created by BRC.

It is interesting the authors conducted no statistical analysis on the comparison of measured and predicted impact force, g's, and neck loads. This is especially interesting since this paper was published years after the data was collected. They had plenty of time to perform a statistics analysis.

A quick visual review of **Figure 22** shows good agreement between the test data and the predicted data.

The Problem

The problem is the predicted data (Simulated Impacts) is for the dummy, not for humans.

It would have been great it they had ran the model for the test dummy (as they did), and also ran the model based on human parameters.

It would have been very interesting to compare the impact test data and the predicted data.

Plus it would have also been interesting to compare the predicted human data to some of the the injury measures.
Basically BMC proved the mathematical model comes close to matching Hybrid III impacts, but we still have no idea what human impact forces, g's, and neck axial loads might be.

Appendix H

Blunt Trauma

Prehistory of Scott's Underwater Head Impact Paper Concerning Blunt Trauma

The 1989 NBSAC report stated: **"Propellers present the hazard of cutting wounds and penetrations of the body, while other underwater appendages, including guards (which increase significantly the potential impact area) present the additional hazard of blunt trauma injuries, which are often more severe."** (see pages 18-19 of the NBSAC 1989 report).

The section below is copied from page 8 of this paper
****

The original **purpose of this research (underwater head impact study) is clearly stated** in the Introduction of the preliminary version of Scott's report:

> *"In May of 1988 the U.S. Coast Guard requested the National Boating Safety Advisory Council (NBSAC) to assess the feasibility of using propeller guards to protect submerged individuals from spinning propellers on outboard motors. The NBSAC's report, presented on November 7, 1989, recommended that the Coast Guard take no regulatory action requiring guards on outboard motors (Reference 1). One of the arguments presented against the use of propeller guards was that the "guards may prevent cuts from body contact with a propeller but substitute the potential of blunt trauma injury, which becomes increasingly significant at speeds over 10 mph" (Page 20. Ref. 1)*
>
> *"The concern that the use of propeller guards **may produce a different injury mechanism was based on theoretical analysis with no direct experimental evidence available to support it.** This research program was undertaken to investigate the potential for blunt injury in underwater impacts with cage type propeller guards. This research was sponsored by Mercury Marine and Outboard Marine Corporation (OMC)."*

Summing it up, the 1989 NBSAC study recommended U.S. Coast Guard take no action to require propeller guards on outboard motors in part because propeller guards may prevent propeller cuts but may cause blunt trauma injuries in doing so.

****

Continued

However, the Conclusion of Scott's paper (the SAFE version) makes no mention of what would happen if a person was struck by an open propeller and is full of hedge words as seen in the quotes below:

1. "The results of this study **support** the argument of the NBSAC report that blunt trauma injuries **may** become significant at speeds greater than 10 mph."

2. "The limited analysis **suggests** that, at impact speeds greater than 10 mph an impact between a submerged head and a lower unit **can** produce head and neck injuries."

3. "The engagement action **may** occur in impacts to other areas of the body when the steel wires of the guard engage the soft tissue of the impacted area."

4. "This engagement action **may** cause high biomechanical forces to be generated at sites away from the impact site by preventing the impacted area from rotating out of the path of the guard."

5. "Impacts to the side the guard at speeds greater than 15 mph **may** produce a loss of consciousness.

Since Scott's Paper

The boating industry itself confirmed there was still no experimental data to confirm their blunt trauma statements in a 2000 Boating Industry International article.[33]

"Prop guards may cause injuries too. **Though still to be tested thoroughly, speculation is** that a boat equipped with a prop guard moving faster than idle speed would cause as much injury as a boat without a prop guard."

In 2010 the Brochtrup vs. Mercury Marine case once again confirmed Scott's research did not find blunt trauma to be worse than being struck by an open propeller. Per Scott's own testimony in the Brochtrup trial:

Question "You did not do any testing to determine the relative severity of blunt trauma vs. cutting from a propeller blade during that test, did you?"

Answer - "Correct"[34]

One Specific Propeller Guard

We should not forget all of Scott's work was based on one specific propeller guard. No testing was performed with any other propeller guard. No efforts were made to extend this research to any other propeller guard.

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[33] Prop guard regulation may be coming. Boating Industry International. June 2000. pgs 36-39. See pg. 39.

[34] Brochtrup vs. Sea Ray and Mercury Marine transcript. U.S. District Court. Western District of Texas, Austin Division. Case 1:07-cv-00643-SS Document 341 filed 7/19/2010. See page 143 of Scott's testimony in the trial.

The END